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COLOR RESEARCH FOR VISUAL DISPLAYS.(U)

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# COLOR RESEARCH FOR VISUAL DISPLAYS

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FINAL REPORT



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the results of three complex multiple task experiments intended to compare the effectiveness of color coding in visual displays against coding by achromatic letters, digits, and shapes. The results of these three experiments are then integrated with previously reported research to provide a comprehensive assessment of the potential advantages and disadvantages of color coding.

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## NONTECHNICAL SUMMARY

Because of technological advances in visual display design, the question of the effectiveness of color as a visual code is of great current interest. This investigation was conducted, therefore, as an attempt to evaluate the effectiveness of color coding relative to achromatic letters, digits, and shapes. The basic approach was through an analysis of the literature and a comparison of the effects on simple task performance of presenting information by these four methods. The laboratory work was done with three classes of comparisons: (1) when the tasks were performed singly, (2) when the tasks were performed in irregularly alternating combinations, and (3) when the tasks were subtasks in a complex air traffic control task. Another experiment, not in that series, compared the performance of color defective subjects with those having normal color vision in a search task in which the color stimuli were totally irrelevant, but interfering with target acquisition. The results of the 14 experiments conducted provided no basis for concluding that color has any peculiar advantage or disadvantage to task performance that makes it different from the achromatic codes used for comparison. It is concluded that it is not <u>color qua color</u> that should be of interest or concern, but the fact that color can be used as one more dimension along which information can be presented. Whether it should be used for that purpose depends upon how it compares for any particular purpose and in cost to other possible codes.

The report also emphasizes the differences between image resolution and the further informational processing of acquired images by the user. The former depends upon such factors as contrast, size, etc. The latter depends upon the information coding properties of displays and symbols within displays. To that end ten general principles or working hypotheses of information coding are presented. It is concluded that color does not differ from other possible coding sets in that they all follow these principles.

Remembering that any one coding set could be made to appear advantageous or otherwise, Table 1 may be used to evaluate the differences that have been reported in comparing color coding with achromatic codes. The table is a revision of a similar table prepared by Christ (1975) altered however to incorporate the experimental work of this project.

TABLE 1

Mean Percent Difference Scores for the Use of Color[a]

ISOLATED TASKS

| Single Code | Choice Reaction Task (Response Time) | Search/Locate Task (Response Time) | | Identification-Memory Task (Response Time) | | Identification-Memory Task (Accuracy) | |
|---|---|---|---|---|---|---|---|
| | | Density 4 | Density 12 | Density 4 | Density 8 | Density 4 | Density 8 |
| Letters vs. Colors | 1.3 | 1.6 | 27.3 | 11.2 | 8.4 | -10.2 | 2.9 |
| Digits vs. Colors | -4.1 | -0.2 | 21.5 | 1.5 | 6.3 | -15.0 | - 1.0 |
| Shapes vs. Colors | 0.4 | -2.8 | 8.2 | 0.7 | - 0.1 | - 4.4 | 1.1 |
| Dual-Code (Constant Background) | | | | | | | |
| D/L vs. C/L | | 4.3 | 21.9 | 8.9 | 17.3 | - 4.6 | 0.2 |
| S/L vs. C/L | | -0.9 | 10.6 | 8.3 | 8.8 | - 4.9 | - 9.2 |
| L/D vs. C/D | | 8.7 | 26.2 | 25.4 | 27.4 | - 1.9 | 0.0 |
| S/D vs. C/D | | 4.2 | 12.9 | 12.4 | 15.7 | - 7.0 | - 5.1 |
| L/S vs. C/S | | 0.4 | 11.7 | 9.8 | 13.7 | -15.0 | -17.0 |
| D/S vs. C/S | | 0.9 | 10.0 | - 9.7 | - 8.7 | -13.1 | - 7.5 |

TABLE 1 (Continued)

COMBINED TASKS

| Single-Code | Choice Reaction Task (Response Time) | Search/Locate Task (Response Time) | | Identification-Memory Task (Response Time) | | Identification-Memory Task (Accuracy) | |
|---|---|---|---|---|---|---|---|
| | | Density 4 | Density 12 | Density 4 | Density 8 | Density 4 | Density 8 |
| Letters vs. Colors | 4.6 | 10.6 | 6.3 | 3.7 | 13.9 | 3.5 | -4.8 |
| Digits vs. Colors | 0.1 | 5.5 | 4.4 | - 7.5 | 5.7 | 5.2 | 0.7 |
| Shapes vs. Colors | 2.0 | 7.0 | 6.0 | 7.5 | 6.1 | -1.6 | -2.8 |
| **Dual-Code (Constant Background)** | | | | | | | |
| D/L vs. C/L | 3.8 | 10.1 | 15.5 | -36.8 | 20.7 | 0.5 | -6.1 |
| S/L vs. C/L | 0.7 | 5.4 | 4.2 | 1.5 | - 2.4 | -0.6 | -2.5 |
| L/D vs. C/D | 9.5 | 8.8 | 16.5 | - 6.4 | 10.3 | 0.2 | -2.5 |
| S/D vs. C/D | -1.3 | -0.8 | 5.2 | 1.9 | 5.6 | -1.0 | -0.7 |
| L/S vs. C/S | -1.8 | 1.7 | 9.1 | -11.5 | 13.8 | 4.2 | 6.1 |
| D/S vs. C/S | 3.8 | 3.2 | 10.5 | -41.1 | 10.1 | 3.6 | 8.9 |

[a] Difference scores were determined by subtracting the performance obtained with color coding from that obtained without color coding and then dividing that difference by the performance without color. Abbreviations are as follows: C = color dot, S = geometric shape, D = digit, L = letter. For dual-code displays the letter preceding the slash represents the target code; the letter following the slash represents the nontarget background code. In all cases, a positive score indicates a relative gain with the use of color, a negative score a relative loss.

## PREFACE

We wish to express our appreciation to Commander Donald C. Hanson, contract monitor, for his patience, encouragement, and skill as a communication link and filter between the contingencies and exigencies of military aircraft cockpit design and the contingencies and exigencies of laboratory research. We are also very appreciative of the contributions of Nancy E. Hutchcroft who assisted throughout the entire investigation in the collection and analysis of data and who drew all of the figures, and to Julie Goodrich, typist, editor, and keeper of the style manual.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued-1)

TABLE OF CONTENTS (Continued-2)

LIST OF FIGURES

LIST OF FIGURES (Continued-1)

COLOR RESEARCH FOR VISUAL DISPLAYS

This report presents the results of an investigation of the effects on human task performance of color coding in visual displays. The report contains two parts. Part I offers ten selected general principles of coding for human information processing which apply to any coding technique. The advantages and disadvantages of color are considered in terms of these principles and the question of whether color as a coding method offers something more than would be expected of any other coding method is raised. The principles are also used to evaluate how color might be used most advantageously if it were used, and under what conditions color might be detrimental to performance. Part I then presents the results of the entire investigation first by summarizing our previously reported findings, and secondly by presenting the results of new experiments. All of these results are then evaluated and conclusions are drawn.

Part II is a detailed presentation of the new experiments presented in abbreviated form in Part I.

## PART I

### Color and Visual Information Coding

Color may be useful in visual displays in three ways. First, it may provide pictorial or scenic realism and a visually pleasant experience. That is, it may provide an esthetic stimulation as opposed to the "bleakness" of a black-and-white or monochrome display. Experienced operators such as aircraft pilots and photo-interpreters have been shown to prefer colored displays for that reason. The evidence, however, does not suggest that the esthetic gain is associated with improved task performance although the operators may believe the contrary (Christ and Teichner, 1973; Christ, 1975).

Secondly, color might be used in an attempt to overcome the effects of image degradation or of masking effects due to clutter or other visual noise. In this case, the possible use of color represents an attempt to aid the image-resolving sensory process. The idea that such aids are possible with color appears to be one of the assumptions underlying the advocacy of color in image-type or pictorial displays. Suppose, for example, a black-and-white display having a target image of low brightness contrast. As a result the contours of the image are difficult to resolve. Would the situation be helped if the target were green and that color were different from that of its immediate surround? Studies of contrast show that brightness contrast is maximum for colored targets when the target wavelength and the surround wavelength are the same (e.g., Jameson and Hurvich, 1959). Thus, color should not help.

Studies of the effects of chromatic contrast on visual acuity have generally shown that color contrast does not contribute to the spatial resolution of images relative to brightness contrast unless brightness contrast is very small. For moderate levels of brightness contrast a colored object may be more or less visible than a corresponding neutral object depending on the colors and sources involved (e.g., Guth and Eastman, 1970). Given that the display would contain at least moderate levels of brightness contrast, it would be expected, that at the most, color in the display would not help, and that it could even be detrimental to contour detection compared to a black-and-white display or to a monochrome display.

A third possible use of color is in the coding of informational events in visual displays. For this purpose color may be used to represent meaning in the same sense that a letter or numeral or shape might be used. Color may also be used to identify areas or visual events of interest. Suppose for the example above, that the target was colored green and that the green color could be recognized readily even though there were difficulties in contour resolution. In that case even though resolution were poor, the target could be identified if green were a necessary feature of the target, and if non-targets were not also green. In this case color is a feature code.

The distinction between the second and third possible use of color is one between sensory processing of visual data to the point of image acquisition and a perceptual-cognitive processing of the acquired image. The former depends upon contrast, size, etc. The latter depends upon the amount of information in the stimulus and other characteristics of the stimulus that we shall consider below. For the example used, a successful target identification is desired in both cases. However, without an appropriate experimental arrangement, no conclusion about which process is involved is possible. That is possible only by designing the experimental procedures so as to preclude the effects of either the sensory or the informational variables. The data that we shall be reporting were collected with essentially noiseless displays having images resolvable at well above threshold sensory resolution. There was never a question of whether the subject could resolve the image or whether he could provide a detailed description of the targets, non-sensory conditions permitting. The investigation, therefore, was concerned with the use of color for coding and not for image resolution.

## Color as a Coding Dimension

In this section we summarize the advantages and disadvantages of color coding in terms of ten principles of human information processing. Some of these principles are better developed than others so that they may also be viewed as ten working hypotheses which we are proposing. Since a comprehensive presentation of human information processing applied to the design of visual displays is beyond the scope of this report, the discussion is restricted to those principles which appear to be most important and most applicable to the present problem.

Principle 1: The Principle of Attensity.

Attensity is the attention-getting quality of a signal (Klein, 1964; Titchener, 1910). Attensity depends upon three general factors:

1. The greater the differences between the signal and other signals presented either simultaneously or successively, the greater the attensity. It is not the brightness of a signal which is attracting; it is the difference in brightness between that signal and other signals, or, for a signal by itself, between the signal and its surround (contrast). However, a signal at high contrast has less attensiveness in a set of other signals which are also at high contrast, than when alone. Furthermore, the larger the signal set displayed at one time, all at high contrast, the less the attensity of any signal in it. It is, therefore, not the contrast as such, but the difference in contrast which is important. Similarly, a colored symbol has greater attensity when it is the only colored symbol than when other symbols are also in color, and the more similar those other colors, the less the attensity of any one.

For other coding sets such as shapes which do not fall on an intensive dimension, there is reason to suppose that this aspect of the principle can be expressed in terms of the critical features of the signal. It is likely that differences between signals in the points and lines of shapes determine attensity levels. For example, a hexagon may be more attensive when next to a circle than when next to a pentagon.

2. The greater the novelty or surprise value of a signal, the greater the attensity. That is, the lower the probability of signal occurrence, the greater the attensity.

3. Habituation to a signal decreases its attensity. The more frequently the signal occurs without consequence, the less its novelty, and, therefore, the

less its attensity.

Attensity has critical design implications. For example, the greater the importance of a particular event or the less its probability in a set of symbols, the greater the attention-getting value it requires when it occurs. This implies: (a) important or low probability visual events should "stand out" in the sense of unusual or very different color, or brightness, or movement, (b) all possible efforts should be made to minimize habituation to the event. To achieve that requirement means that the event should not occur in a nearby context or in what might be called a waiting mode. To illustrate, suppose that an arc of a dial-and-needle indicator were colored red meaning danger whenever the needle rested in the arc. Since the red color is always present, the operator may become habituated to its presence and, therefore, have to rely on needle position, as such, as a primary indicator and <u>then</u> color as a secondary indicator. A better display would be one for which the red color appeared only as the needle moved into the arc. Along a related line, some degree of habituation might occur even to the better display if red lights or red symbols were flashing on and off from time to time on nearby displays.

<u>Principle 2</u>: <u>The Principle of Identifiable Code Elements</u>.

The greater the number of unique values or items which can be identified along a dimension, the larger the amount and the greater the flexibility of coding possible. The critical term here is <u>identify</u> since the number of unique elements that can be used to represent different elements of information is limited to those values on the dimension which the individual can name or identify on an absolute basis. The number of values that can be <u>discriminated</u> as different from each other without being identifiable when alone is always much greater.

The absolute identification of color depends to a great extent on wavelength, but it also depends importantly upon luminance or intensity and the interaction of intensity and wavelength (Bezold-Brücke shift). For briefly seen displays, at least of small size, it depends upon Bloch's law as well, i. e., the name given to a small briefly seen color will remain constant only if the total energy (intensity x signal duration) remains constant (Kaiser, 1968). Still other factors such as the color of the target surround which may induce complementary colors of the target (Jameson and Hurvich, 1959; Ishak, Bouma, and van Bussel, 1970), and the general conditions such as intensity differences, wavelength differences, size differences, saturation, etc. will determine the number of discriminably different and uniquely identifiable colors. No one has yet attempted to put all of these factors together to determine how color naming varies with their joint and interactive effects, but it can be estimated that, on the average, identification is limited to about nine colors (Jones, 1962) although with extensive, very specific practice, as many as 20 or more might be possible (Feallock, Southard, Kobayaski, and Howell, 1966). In any case even nine colors is a matter for the future, since current technology appears limited to 3-4 colors on pictorial displays and perhaps, six on discrete indicators. For the present purpose, therefore, we shall assume an upper limit of 4-6 absolutely identifiable colors as the set which could comprise a color code.

Assuming 4-6 colors, the color dimension offers very little for the detailed unidimensional encoding of moderate to large information sources. It certainly does not compare to letters of the alphabet (26) or even digits (10). It does not compare to shape or form coding which has an almost limitless possibility for information encoding. What it does compare to are other physical dimensions such as sizes and brightnesses both of which are in the same general range as color.

On this basis the use of color for information coding should be restricted to small signal or message sets. That may take two forms. First, such sources are generally the case for discrete indicators, warning signals, limited areal demarcation as on maps, and unique designations for 4-6 specific targets. The size of the color set may be adequate for most cases of these kinds. Note that these examples are all of unidimensional coding in that it is the color alone which defines the target or signal or area.

Color as a small code set may also be used in multidimensional coding whether to provide information supplementary to a primary designation, or to provide summary or organized information, or to provide feature redundancy for target identification. All of these are considered in the principles discussed below. At this point, however, it may be useful to illustrate what is meant by the terms.

Consider a display of symbols representing a variety of aircraft. Unidimensionally each available color might be used to designate a specific kind of aircraft. However, many more specific kinds of aircraft can be designated by letters or shapes so that it might be more useful to use color coding to designate more general aspects of the aircraft. One color might be used with all shapes representing civilian aircraft and another color for military aircraft (or friendly and enemy). This is bidimensional coding since the symbols may vary in both color and shape. Color provides a dimension for classifying; the other dimension provides a basis for specific identifications.

Suppose that each color represents a class or category of information as above, but that a particular color (class) is used as a summary encoder. This could be done by using a spot of a given color with a number superimposed on it to mean the number of aircraft in a particular class. Again, this is bidimensional, but here color is organizing or classifying and serves as the code base for the numerical data.

Principle 3: The Principle of Information.

The greater the amount of information (in the Shannon sense) in a code, the longer the processing time required per code element (Teichner and Krebs, 1974b). It is already well-established that color coding follows this principle in common with other codes. Amount of information depends upon both the number of possible values or elements in the code set and their probabilities of occurrence. Note that the principle says nothing about the effect of information on error. This is because in the absence of a time limit within which the responses must occur, for an operator who knows the code, the error rate will be very low (although greater than zero) and can be ignored for our purposes. Principle 3 implies a trade-off between the amount of information that can be encoded and the processing time in terms of the size of the code set. We have already suggested that color will probably be best applied to small or moderate information sources. Principle 3 implies that the size of the set or the signal information should not be greater than the number of events or elements to be encoded. Thus, using letters to encode a two-bit source would not provide any greater information transmission than color, and would cost more by requiring more processing time.

Principle 3 is importantly affected by practice. The less practiced the operator, the steeper will be the information function (Teichner and Krebs, 1974b). A sufficiently practiced operator might show no effect of Principle 3. For a 6-element code set with push-button responses that level of performance would be expected to require approximately one million trials of practice before no further practice effect would be observed. However, the major effects of practice occur in considerably fewer trials (Teichner and Krebs, 1974b).

Principle 3 is so well-established that it can be assumed to operate in any situation, understanding that the function is attenuated by practice. Consequently, in setting up the present experimental procedures, there seemed to be no purpose in comparing six colors against 26 letters, or 10 digits, or some large number of shapes. The issue of whether or not color should be used in visual displays, using task performance as a criterion, is whether it offers something more than what might be expected from Principle 3. To enhance the possibility of answering that question, code sets were compared consisting of the same six colors vs. six letters vs. six digits vs. six common geometric shapes. Subjects used in the experiments were given extensive practice in the hope that the letter, digit and shape sets would be established as six each rather than the original larger set sizes.

Principle 4: The Principle of Input Rate.

As the rate of information transmitted along a channel to a human receiver increases, the rate of correct reception increases to a limiting value (Teichner and Krebs, 1974a). When the input rate increases past that limiting value one of the following happens: (a) the rate of reception remains constant at the limiting rate resulting in varied kinds of errors of omission, or (b) the human establishes priorities which result in a selective reception of data and consequently selective errors of omission, or (c) he attempts to keep up with the increase resulting in errors of commission as well as of omission. What he does will depend upon response requirements, short-term memory requirements, the payoffs and risks in the situation, and skill level.

For visual displays the input rate or load depends upon the amount of information displayed and the rate of change of the displays. The limiting rate varies with the task up to a maximum of over five bits per second for a visual search task involving acquisition of a single unidimensional target symbol in a matrix of symbols such as letters, digits, shapes, or colors (Teichner and

Krebs, 1974a).* For other kinds of tasks the limiting rate is considerably less.

When the human receiver attempts to keep up with increases in input rate, he does so by manipulating the trade-off between speed and accuracy. Errors of commission result from a lowering of the criterion for recognition of the signal. Although lowering the criterion decreases the time needed for acquisition of the signal, it increases the probability of incorrect recognition and of false alarms. To minimize this increase in error probability, the probability of error should be low in the first place. A small set such as offered by 4-6 color symbols will be associated with less error as the input rate increases than would a large set, such as letters of the alphabet, assuming a high level of sensory resolution for both.

Principle 5: The Principle of Chunking.

Although humans can identify on an absolute basis only about 3 bits of information along a physical dimension or 4-5 bits along an arbitrary dimension such as the alphabet, they are able to process large quantities of information if allowed to organize it into discrete organizational units or chunks (Miller, 1956). These chunks are especially important to memory as they are the units which are stored and then retrieved and decoded. A chunk in a particular case might be the stored form of a phoneme or a word, or a shape, or a color, etc. which when decoded results in a larger amount of information. It is probably true that some kinds of symbols are better for memory coding than others, and it is certainly true that the smaller the set the greater the speed and accuracy of both encoding into memory and retrieval from it. The principle argues, therefore, that when multiple signal sets are to be used at one time, or close in

* This value is based on the assumption that the searcher actually scans over each element in the matrix until he finds the target.

time, the smaller sets should be reserved for use as chunking or organizational units, and the larger sets for the detailed information to be chunked. But some codes may be more amenable to chunking some kinds of information than others. There is some evidence that color may aid in the retention of information about category size and spatial location, but not identity (Wedell and Alden, 1973).

Principle 6: The Principle of Redundancy, Irrelevancy and Compulsive Encoding.

In a display of colored shapes in which a target is defined as a blue circle and it is the only circle and the only occurrence of blue, blue and circle are completely redundant. Only one of these is necessary for unequivocal identification. If blue also occurred with all other symbols, it would be totally non-redundant. If blue occurred with the target circle and with some, but not all other symbols, it would be partially redundant (partially correlated with the target definition) and partially irrelevant. If a variety of colors were present, but they varied independently so that they did not correlate with the target definition, color would be totally non-redundant and totally irrelevant. However, non-redundancy can also occur when a target is defined by more than one independent characteristic. For example, if the target were a circle and meant one thing when it was blue and another when it was red, and if blue and red were independent of shape, color (and shape) would be non-redundant, but relevant. Irrelevancy of a degree exceeding approximately 50 percent redundancy impedes both searching and identification (Christ and Teichner, 1973; Christ, 1975). Irrelevancy associated with total non-redundancy also impedes performance. The irrelevant features act as distractors.

The irrelevance principle, as stated, applies to the case where the partially irrelevant feature is exactly the same as the target feature. However, that feature may be on the same dimension, yet not be exactly the same value on the dimension. The more similar it is to the target feature in attensity the greater the interference to target searching. The more similar it is physically the greater the interference to identification.

In general, the fewer the irrelevant items in a display the better. Sometimes, however, for high density, multipurpose displays, the information displayed may be appropriate for more than one task. This would be the case if, for example, the same display contained both weather information and tactical information. In that case, the color, blue, could have two different symbolic meanings and could provide irrelevant information in the processing of each information set although in each case, it might also be relevant. The ideal solution for this kind of presentation is to use non-overlapping codes, i.e., if color were used for one information set, it should not be used at all for the other. A second-best solution is to use colors for both, but to select the colors for minimal similarity.

Total target feature redundancy aids performance. A multidimensional target whose features do not appear anywhere except on that target will be acquired most quickly and identified with the least probability of error. On the other hand irrelevant symbols having no features in common with a target (zero target feature redundancy) will be processed to some degree anyway. Furthermore, the processing time of irrelevant features (or symbols) will increase with their variety, i.e., the amount of irrelevant information. People are compulsive encoders and follow Principle 3 applied to irrelevant information (Teichner and Krebs, 1974b).

Principle 7: The Principle of Processing Priority

Certain code sets take a processing priority over others. For the processing of multidimensional targets, the highest priority format is language. A word in color or at high brightness or large size will be read to the exclusion of the color (brightness, size) so that if the color provides either supplementary or conflicting information, it may be overlooked, or at least, it will rarely be processed first, nor will the signal be processed as an integral or whole unit (e.g., Shor, 1971). No information is available about other priority weightings, so it is not known whether shapes, letters, and digits will act in a manner similar to words with respect to color. That they might is suggested by the assumption that the word priority effect depends in the normal adult upon a vast overlearning. Naming of letters and shapes is likely to be less overlearned and the naming of digits probably falls somewhere in between. Assuming the naming of any of these to be overlearned compared to color naming, they would all have some degree of priority over color.

Principle 8: The Principle of Integrality.

The multidimensionality of a target may be responded to as an integral unit or the features may be processed separately. The difference depends upon a set of other principles formulated primarily by Garner (1974) and his associates which cannot be explicated here, but which should be noted.

Principle 9: The Principle of Temporal Order.

The greater the temporal difference between two signals in a display, portions of which are changing in time, the greater the probability that their temporal order will be discriminated. This refers to displays in which some symbols might be replaced by others and there is a need to know which of two currently present symbols arrived first. If the time difference of arrival is small, the operator may not be able to discriminate the temporal order even though he may sense them as non-simultaneous. We know that the time difference interacts with intensity differences, and we hypothesize that it also interacts with other differences among which may be size differences, color differences, and shape differences. If the hypothesis is correct, the greater the differences, the greater the probability that the correct temporal order will be known.

Principle 10: The Principle of Practice.

With sufficient practice at a task involving a complex, high speed input and a complex high speed output demand, the detrimental effects of irrelevant information, and of too high an input rate (within limits) are overcome. This is the result of four processes which become more effective with practice: (a) the operator learns what to expect and, therefore, how to change criterion level (or tune out or filter irrelevant signals) at an early stage of processing, (b) frequently occurring signals requiring quick actions become responded to "automatically", i.e., they do not have to be put into a short-term storage and then retrieved, (c) less frequent signal events become encoded into short-term memory more effectively which is to say they are encoded quickly and for maximum relevance to the required responses, (d) information held in memory is put into a priority established queue and retrieved in accordance with the dynamics of the situation. To understand the importance of this principle as well as the entire question of coding, it is necessary to understand that in a high speed, complex, dynamic display-response situation, the operator is almost always working from his memory of the inputs of various sources and from operations performed on the stored data. In fact, if that were not the case, the problem of display coding would be relatively simple; the operator would respond automatically to each successive event in real time. This principle interacts with all other principles.

Based upon the above principles we can conclude that color coding could have the following advantages and disadvantages:

Advantages

1. It could be useful as a chunking unit to organize information. This is

partly because the number of available different colors will be small. However, it also has the property of being able to code large areas (also true of brightness) and, therefore, may be advantageous in demarcating areas of interest as on maps.

2. Because the number of colors is small, it could be particularly effective as a means for coding low probability or very important events. This may be especially aided by the attensive properties of color providing the color is not subject to habituation or partial redundancy. This advantage may be most useful for acquiring targets in crowded displays and for use as warning signals or discrete commands.

3. Color could (or could not) offer a unique value for encoding and storing information in memory.

Disadvantages

1. Color is not useful as a source of detail for sets greater than six as it takes on few values.

2. Color may be especially interfering when it is irrelevant or partially redundant. That is, it may be a very effective distractor.

3. Color may not provide sufficient differences to avoid interference with temporal order discrimination.

In addition to the disadvantages indicated, color as a symbolic event has sensory limitations, two of which should be mentioned in addition to those implied earlier:

1. It cannot be used in the visual periphery.

2. It requires larger symbol sizes for symbol identification than black-and-white symbols. Furthermore, the size requirement increases, the more different colors used and/or the greater the display density (Cahill and Carter, 1976). Consequently it may be no more effective than the size dimension alone.

## Review of Previous Reports

In an effort to analyze the problem of color coding and to quantify the differences between color and achromatic codes on performance, the literature on visual searching performance and identification was used as a data base (Christ and Teichner, 1973; Christ, 1975). The data of each task were classified into studies of unidimensional (target definition using only one feature coding set) and multidimensional coding, studies involving partial and complete redundancy, and of studies from which the interfering effects of irrelevant colors could be assessed. The percentage of gain or loss in performance using color was compared within classifications against coding by brightness, size, geometric shapes, other shapes, letters, and digits. Three general conclusions, to be subsequently qualified, appeared to characterize the data available:

1. From a total of 59 experimental comparisons over a wide range of different conditions color has provided a generally consistent advantage in searching for a target.

2. From a total of 132 experimental comparisons of identification performance, the data suggest that color might be better for identifying targets than size or brightness, but either no better than, or poorer than, the other coding sets.

3. The data available are not sufficient to draw an empirical conclusion about the possible interfering effects of color in the detection or identification of targets defined by other coding features.

The first two conclusions required some important qualifications:

1. The range of findings, scored as percent difference of color against another code as a control, was very wide. The number of experiments of a given kind was also highly variable. Thus, it was difficult to determine effects very

specifically. Rather, it was necessary to "feel" the weight of the evidence. This was especially true of identification since the first conclusion was highly consistent.

2. In essentially all cases the data were based upon subjects who had had little practice at the task. It is possible that with sufficient practice the differences obtained might disappear. If so, any advantage of color might have to be limited to its use as a training aid rather than a design factor.

3. The data were generally obtained under conditions of relative low signal input rates and only with simple tasks. It is possible that with greater input rates and tasks performed under more complex task conditions, the differences reported might change.

4. Few of the studies reported were designed to provide more than a simple test of color versus something else. As a result the contribution of the literature to the development of general principles either of coding or of color coding is small. Furthermore, since that is so, the results do not permit a decision about whether <u>color qua color</u> is a variable or whether color falls under the general rubric of information coding principles. Thus, the first conclusion might be predictable from general principles, and therefore, code sets other than color might be developed with the same advantage.

As a result of these and other questions that could be raised, it appeared necessary to conduct new experiments which, at least taken together, might obviate the qualifications. In addition, a number of knowledge gaps other than the effects of color were identified which suggested a need for specific kinds of data.

The first and foremost question was whether color provides a unique quality for coding displays which makes it different from other code sets. If so, the foregoing information coding principles would not apply either in part or as a whole to color coding. In an attempt to answer this last question as directly as possible, the Principle of Irrelevance was applied to a visual search task. Subjects were required to scan matrices of inked shapes which varied systematically with respect to kind of shape, size, and color (red, green, blue, and black). The same searches were carried out with the matrices reproduced by Xerox so that only some contrast differences and no color differences remained. The originally red and black symbols were now indistinguishable as were the originally green and blue symbols. However, the two pairs could be discriminated from each other. As a result the black-and-white reproduction contained two levels of contrast randomly arranged within the matrix. In comparison, the original matrix contained four colors of which one was black also in a random arrangement.

Two groups of subjects scanned the matrices in a manner allowing identification of the symbols actually inspected. The measure to be discussed is the percentage of non-colored, or black, outlined shapes that were to be detected, but were missed. Thus, the physical stimulus was identical for both, but neither red nor green could be identified by the color defectives. That this was actually the case was demonstrated when the matrices were to be scanned for color as a target feature. Normals made few errors of identification; defectives made a large number of errors except when blue or black was the target color. This does not mean that the defectives could not discriminate between red and green. Those features were seen as different grays, or black at different contrasts.

The critical comparison for our purpose was the percentage of black targets not detected when color was totally irrelevant. The results indicated that both color normals and color defectives performed equally well when the colors were actually present, and when the Xerox copy was used. Since the defectives saw three shades of gray (i.e., three brightnesses or three contrasts) and one color (blue) whereas the normals saw four colors, there should have been a difference in performance between the groups with the colored matrices, but not with the Xeroxed matrices if color has unique effects. If color has any special properties its interfering effects should have resulted in more target omissions by the normals with color present. On the other hand, if the variable involved was the sheer number of irrelevant stimuli, no differences between groups should have been observed since there were four such stimuli when color was present for both groups and two with color absent. It appears, therefore, that it was the number of irrelevant stimuli or the amount of irrelevant stimulus information that was important and not color as such. Additional support for this conclusion may be adduced from the finding that performance with the Xerox copy (one bit of irrelevant information) was better than with the original copy (two bits) for both groups. Since these results could be predicted from the Principle of Irrelevancy without regard to color as such, they provide no support for viewing color as having unique properties advantageous for target acquisition. When applied to the conclusion drawn above from the literature, the finding that color aids visual searching may be suspected to be the result of a confusion of the informational properties of the color code set with assumed special attensive properties of color. That does not mean that color could not be used to advantage, but that the advantage might now be understood and maximized.

There is still a need to study color as a coding dimension in the light of coding principles so as to learn how best to use color when it will be used. For this reason, and for those given earlier, a series of experiments were run (Christ and Corso, 1975) using three different kinds of tasks with different code sets; letters, digits, familiar geometric shapes and colored dots. The subjects were practiced on the tasks at frequent intervals over a period approaching one year and, consequently, were very practiced at all three tasks and experienced with all of the experimental conditions.

The tasks used were the choice reaction time (identification) task, an identification task involving short-term memory, and a search and locate task. Each will be described briefly.

Choice reaction task. This is one of the oldest and still most widely used tasks in psychology. The subject is presented with a signal which is one of more than one possible signal that might occur. As fast as he can do so, he responds by indicating which one of the possible alternatives is the signal. The most frequently used mode of responding is by pressing the appropriate one of a set of buttons each button being coded uniquely for each signal.

The quantitative relationships that describe performance on this task are well-known (Teichner and Krebs, 1974b). In particular, the reaction time (time from signal onset to response onset) is known to be linearly related to the amount of signal information, i.e., it follows Principle 3. In fact, it has been studied extensively with a large variety of signal sets, including color, but less so in comparisons of signal sets within the same group of subjects. We know that color follows the principle, but it is possible that color is processed as a signal at a different rate than achromatic codes. If so, the slope of the line relating reaction time to number of equiprobable alternatives would be different and the limiting number of practically feasible code units might be more or less than that of achromatic codes. One purpose of this investigation was to test that possibility.

In considering that test, it is conceivable that the intercept might be different than that of achromatic codes either in addition to a slope difference or without a slope difference. Such an event could not be interpreted easily since intercept differences are based at least partly on the particular sampling of the units of the code set. That is, if the discriminability of the color values selected for the set was greater or less than that of the achromatic code units used, the intercepts of the information functions might be different. Such differences reflect a lack of experimental control for our purposes. A lack of intercept differences does not imply no error in the experimental comparison, but it does imply that whatever factors were uncontrolled, they were not important to the reaction time measure. The problem is not trivial because the size of the dots we used for the color code was less than the size of the letters, digits, and shapes (which were all equal) and there were small differences in the brightness of the chromatic and achromatic codes. If those factors had effects on the reaction times, their effects would be on the intercept of the function, but not the slope. The slope provides an uncontaminated measure of the process going on regardless of effects which may affect the absolute level of the curve.

The choice reaction time task was set up as part of a more complex console to be described later. Eight subjects, highly practiced as already noted, responded with button-presses to the appearance of a signal known in advance to be from a particular code set. Over a variety of experimental sessions appropriately arranged to control for order effects, the set size was either three possible signals or six possible signals. All of those signals arrived at a single position so that there was no uncertainty about where the signal would be, only what it would be. However, since position uncertainty is a very important consideration in the design of displays, an additional experimental arrangement was included which permitted a comparison of the effects of fixed versus random positioning of the signal on the display.

Figure 1 presents the results showing reaction time related to the number of alternatives in the code set for the position-certain and the position-

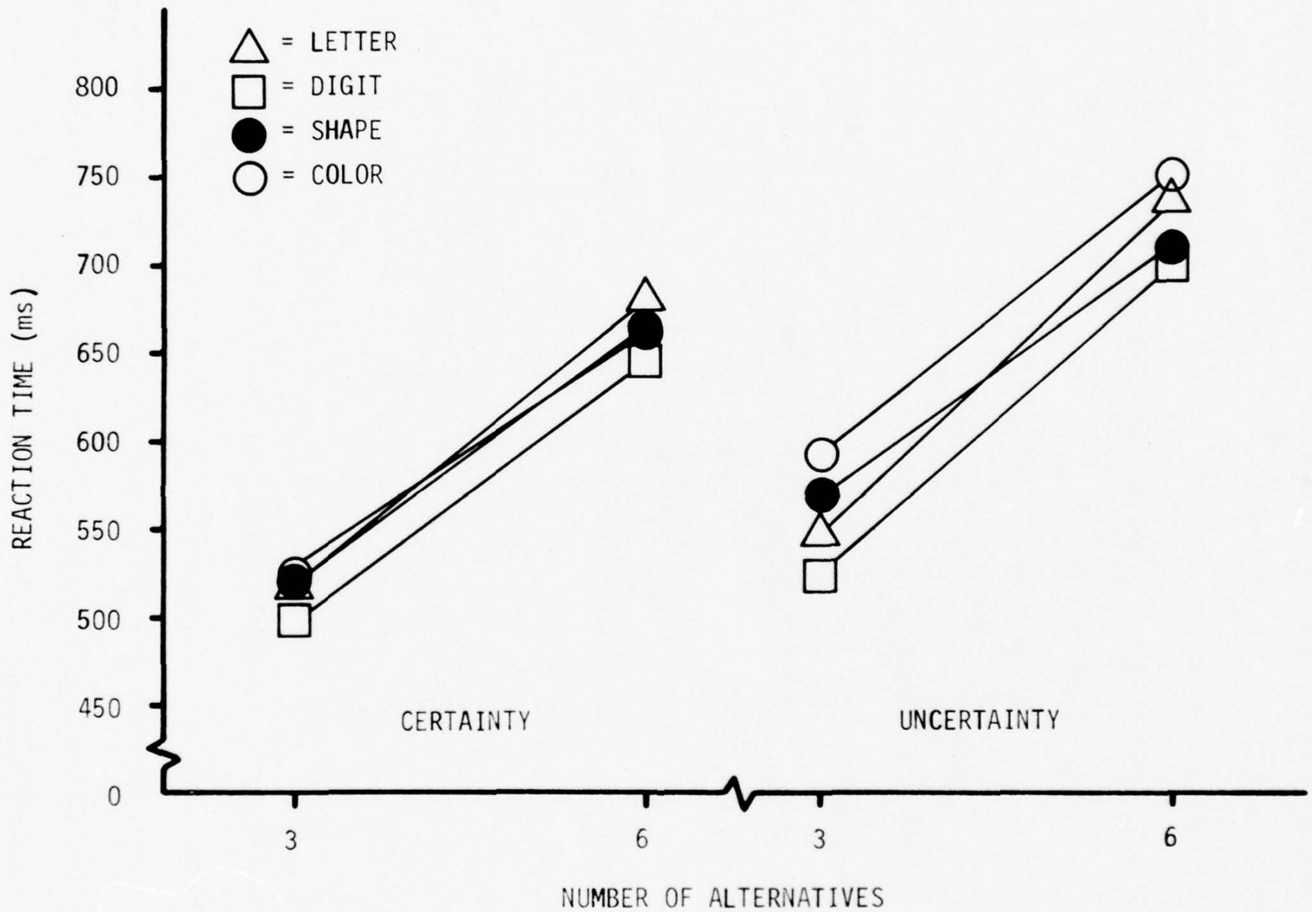


Figure 1. Choice reaction time as a function of the number of target alternatives separately for each target code set and for certain and uncertain target positions. (Data from Christ and Corso, 1975)

uncertain signals. The former is based upon 384 trials per subject per point; the latter is based upon 336 trials per point per subject or 3072 and 2688 measurements per point. The figure does not suggest slope differences among the codes for either position-certain or for position-uncertain signals. The effect of amount of information shown in the figure is the expected increase in reaction time with an increase in the number of signal alternatives. Since slope differences do not appear, it may be concluded that the information function is the same for all codes. For the position-certain task, color is at an intercept level that is about medium in the range. The best performance is associated with digits and this is consistent with previous studies (Teichner and Krebs, 1974b). It appears, then, that the differences in the size and brightness of the color dots did not affect the color information function.

Digits also provided the best performance with position-uncertainty, and in this case, it may be seen that the color code was clearly and consistently associated with the poorest performance. It appears, then, that if color has characteristics which differentiate it from achromatic codes one of them is related to the effect of position-uncertainty.

Search and locate task. This particular task was more complex than the ordinary visual search task in that the subjects were required not only to find the predesignated target on a display, but also to report its location. As we did it, the target was one of the six possible elements of a given code set. There was always only one target on the display and for each sequence of trials, the total density of the display was either four or twelve symbols. Over any sequence of trials the target's position appeared an equal number of times in each of 16 possible display positions. The subject responded as soon as possible by pressing one of four buttons as a means of indicating in which of the four quadrants of the display the target was located.

Again we note that differences in slope, this time of the density function, can be used to infer something about differences in the underlying process or processes. The greater the slope of the line relating response time to display density, the more rapidly the ability to perform the task will reach a limiting density.

The results are shown in Figure 2 which shows a smaller slope for color than for the achromatic codes. Shape coding had the second smallest slope. Thus, at least for this set of colors, it can be expected that the limiting density is greater for colors than for the achromatic codes. In different terms color should be relatively advantageous for designating items or targets to be found in high density displays. That result is in agreement with our previous discussion of the literature. The effect may reflect a greater color attensity, or since letters and digits and geometric shapes are basically all shapes they may have been more confusable within their sets than the colors were.

Identification-memory task. Although the choice reaction task is one of identification, no memory is involved because the stimulus remains present until the subject responds. In the identification-memory task the display was available for a limited time, a time so short that the display was no longer available when the subject initiated his response. In addition, the display contained either four or eight code elements displayed for 400 and 800 ms* respectively, all of which had to be identified so that display density was also a variable.

The arrangement was such that if for some reason the subject did attempt to initiate his response before the end of the time limit, the display was automatically terminated. Such attempts were infrequent, however, since on the average only one such attempt occurred out of every 50 trials.

Absolute accuracy was greater for the Density 8 displays than for the

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* milliseconds

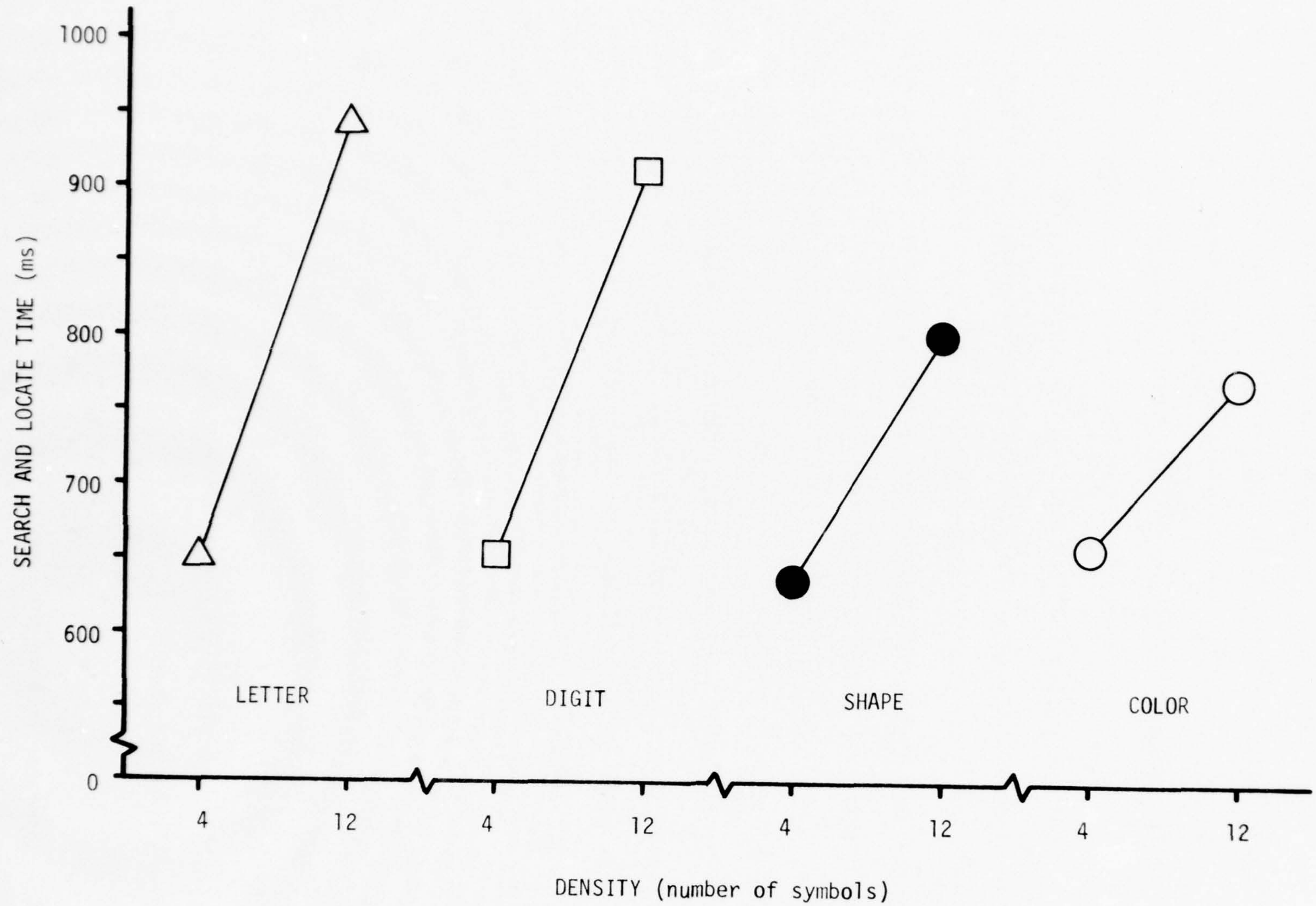


Figure 2. Search and locate time as a function of display density separately for each target code set. (Data from Christ and Corso, 1975)

Density 4 displays being on the average 6.1 correct responses compared to 3.5. On a relative basis, of course, performance was better with the Density 4 displays. At Density 4 there was no difference in accuracy between the different codes, but at the higher density slightly greater accuracy was obtained with digits than with the other three codes which were equally accurate.

The results indicated that the response time to letters was longer than to digits, shapes and colors. The other three did not differ significantly from each other. Thus, the results suggest no particular advantage or disadvantage of color when several targets must be identified with a very limited viewing time and with a memory requirement.

Summary of previously reported work. The experiments reported so far suggest the following conclusions:

1. The interfering effects of irrelevant color symbols acting upon achromatic symbols in the same display are not related to the fact that they are color, but rather to the fact they they are irrelevant stimuli. Color, like other codes, follows the Principle of Irrelevancy. Presumably, the converse is also true, that is, any apparent positive effect observed with a color code is due not to anything peculiar to color, but to the fact that the elements provide a code.

2. In a dense display, a colored target may be acquired more quickly than an achromatic target of the sorts studied. The attensity of any code can, however, be manipulated so as to provide the advantage to any achromatic code as compared to color. Therefore, again it does not seem to be color qua color that provides an advantage.

## Multiple Task Experiments

The above conclusions still need to be qualified by the fact that they apply only to simple discrete tasks performed in isolation. A more realistic laboratory representation of most operational situations, e.g., piloting, would be one in which a number of tasks must be performed of which a given simple task is but one. The logic of the new experiments to be reported approaches that representation in two ways. In one, the simple discrete tasks are presented in random order. Since there were no contingencies among the tasks, the only meaning the tasks could have for the subjects was whatever they had when presented in isolation. This is called the combined task situation. Another way to approach a more realistical representation of an operational situation is to give the simple tasks meaning within the context of a total task activity, i.e., to integrate them into a more complex set of activities. This is the integrated task situation. The question was whether within these more complex operations color coding might reveal effects not seen in the isolated tasks.

Two combined task experiments were run in which the subject had only to respond to the simple discrete tasks as they were demanded. A third, integrated task experiment required the subject to monitor and effect changes in the parameters of aircraft presented in a continuous air traffic control problem and, in addition, to respond as requested to the same simple tasks as subtasks of the total problem. Thus, the overall investigative effort provided an opportunity to compare the same simple tasks in isolation (cf., Christ and Corso, 1975), when they were combined non-contingently over a series of discrete trials, and when they were combined in an integrated manner in the context of a complex continuous task. As used, the integrated task also allowed an evaluation of color as a multi-dimensional feature.

In the isolated task experiments and in the two combined task experiments the displays contained elements from one of the four coding sets previously described (letters, digits, familiar geometric shapes, or colored dots) or from one of the six dual-code sets (e.g., letters and digits, or digits and colored dots). However, because the colored dots were smaller than the achromatic codes, color was completely confounded with size when the colored dots were used simultaneously with other codes. The data do not suggest that this produced effects that would have been different if equal sizes had been used, but in order to avoid a possible major qualification of our conclusions about color, we shall present only the single code display data in Part I. Part II presents all of the data obtained including the dual code display data. We note that the dual code data would not have changed our major conclusions had we used them.

In all of the experiments the displays appropriate for each of the single tasks were located in different positions around the periphery of the display console. A central display consisted of a 16-cell matrix onto which four to twelve coded elements were projected. The matrix display was present 500 ms before the single task display, and both remained on together for a maximum of 1500 ms. In the combined task situation the subjects were required to monitor all of the displays.

In the integrated task situation the matrix display was presented continuously, and the coded elements in that display could be repositioned in discrete steps to represent the movement of an aircraft from one location to another adjacent location. In this situation the single task displays were presented at random intervals and remained on for a maximum of 3000 ms or until the subject made an appropriate response.

Experiment 1: Combined Task I

In this experiment the requirement to respond to each of the three different tasks (choice reaction, search and locate, and identification-memory) occurred on randomly selected discrete trials. There were 30 trials in a sequence of which ten were for each task. There were a total of fifteen 30-trial sequences per experimental session and seven sessions. Discarding the first session as practice, and discarding the ten 30-trial sequences within each session that were used for dual-code displays (cf., Part II), the experiment provided over 480 experimental trials per subject. The subjects were those used in the previously reported isolated task experiments, and, therefore, were thoroughly familiar with the tasks and codes. They had only to learn the requirements of the combined task situation.

Choice reaction task. The results for this task indicated that overall, there was a large increase in reaction times compared to the same task in isolation even though accuracy remained very high. There were no differences between the codes that were statistically significant. Thus, all codes had the same slope and intercept for the information function.

Search and locate task. As before, search and locate time was longer in the larger density condition, but there were no differences among codes. This indicates that the slope and intercept of the density functions were the same. Neither density nor code had an effect on accuracy.

Identification-memory task. While subjects were more accurate with the lower density displays, there were no significant differences in accuracy among code sets. The mean time to report each of the code items was affected by density and code. Subjects reported items from the higher density displays faster than items from the low density displays. At Density 4, the mean response time for digits was faster than for any of the other three codes. At Density 8 the four codes were ordered from slow to fast as letter, digit, shape, and color; the only statistically significant difference was between letters and colors. Thus, color was associated with the best performance at the high density display condition, but not at the low one.

These results indicate that for the more complex conditions of this experiment, the differences between the codes decreased for the choice reaction and the search and locate tasks compared to those tasks in isolation. On the other hand, for the identification-memory task, color became advantageous at the higher density. The data suggest that there may be a gain in having used color in the high density displays, but that the gain depended upon the nature of the task.

Experiment 2: Combined Task II

In this experiment the number of tasks was increased to four (a same-different comparison task was added to the three tasks used in Experiment 1) and the identification-memory task was modified so that both full and partial reports could be required. Both of these changes were added in the hope of increasing the overall input stress to a point at which systematic code differences might appear. The four tasks were presented in random order over 48-trial sequences, each task occurred 12 times per sequence. There were a total of six experimental sessions with 14 sequences per session. Thus, after discarding 7 sequences per session that were used for dual-code displays (cf., Part II), there were over 72 experimental trials per task per subject.

A new set of subjects was recruited and given extensive training before they were run in Experiment 2. The training consisted of practice with each simple task in isolation and with the Combined Task I situation.

Choice reaction task. Accuracy was very high on the choice reaction task trials. There were no effects of density or code on accuracy or on response time.

Search and locate task. Search and locate time was longer in the larger density condition. There was no significant code effect. Accuracy in this task was higher for the less dense display, but the effects of code were negligible.

Identification-memory task. Subjects were more accurate with the less dense displays, and with digits relative to all other codes. An interaction was found between code and density for the mean response time data. There were no differences among codes at Density 8, but response time to color targets was significantly longer than to any other target code at Density 4.

Comparison task. An effect of code was found for both the accuracy and response time data. The colors were responded to less accurately and less rapidly than any of the achromatic codes.

The results of Experiment 2 indicate that the additional input and information processing demands did not lead to any new differences between codes. Where there were differences, color was associated with the poorest performance, as in the comparison task and in the low density identification-memory task. The latter is not consistent with the results of Experiment 1 where color was found to be advantageous at the higher density with the identification-memory task. This inconsistency may reflect practice differences between the subject groups.

Experiment 3: Integrated Task

In this experiment the subject was required to assume the role of an air traffic controller. He had to monitor aircraft symbols continuously and make required changes in certain flight parameters of different aircraft. The flight parameters under the direct control of the subject were altitude, speed, and heading. Detailed quantitative information concerning an aircraft's altitude, speed, and heading could be requested by the subject; this information was presented in digital form in three peripheral displays. Change in any of these three parameters could be made through a numeric keyboard. Concurrent with the air traffic control problem, the subject had to respond, when signalled, to the same four single tasks of Experiment 2. There was no intention of providing any degree of fidelity of simulation of a known air traffic control task, but rather to provide a situation which the subject could accept as a meaningful integrated task within which the simple tasks had a role.

The major coding variable used in Experiment 3 was a letter-digit combination; each aircraft used in the air traffic control problem was defined by a unique letter-digit combination. The simple discrete tasks required the subject to identify, to remember, to compare, or to search and locate these letter-digit aircraft labels. Once the subject had learned to perform the air traffic control problem with considerable proficiency, two other coding variables were introduced to represent two different classes of information. First, the approximate altitude of each controllable aircraft was dichotomized and either shape-coded or color-coded. Secondly, both the approximate altitude and the approximate speed of each controllable aircraft were encoded; shape was used to encode altitude and color was used to encode speed or vice versa. The altitude and speed information was presented in a square and/or circle which surrounded the letter-digit label for each controllable aircraft. If only shape coding were used, the square and circle were white in color; if only color coding were used, one of the shapes was colored red or green.

The question in Experiment 3 was whether or not the shape and/or color coding of two major aircraft flight parameters would (a) aid the subject in his attempt to monitor and control the aircraft and (b) aid the subject in his attempt to respond to the discrete tasks. The latter issue was based on the argument that shape and/or color coding would reduce the stress inherent in the air traffic control problem and consequently increase the subject's ability to respond to the discrete tasks. The results of Experiment 3 can be summed up simply: with practice on the task to the point where the subjects were operating the air traffic control task proficiently, there were no differences in performance on the air traffic control task, or on the simple discrete task that could be related to a difference between the effects of shape and color coding.

There was evidence that the multi-dimensional coding employed in Experiment 3 did affect performance. Response time in the search and locate task and in the comparison task decreased when shape or color was added to the central display to represent the approximate altitude of controllable aircraft. There were no effects of shape and/or color coding on reaction time in the choice reaction task, and response times were non-systematic in the identification-memory task. Shape and/or color coding reduced the accuracy of responses in the identification-memory task, but had no effect on the choice reaction, search and locate, and comparison tasks. Hence, the use of shape and/or color in a multidimensional coding format did have an effect on discrete task performance, but the direction and magnitude of that effect was a function of the task required and the dependent measure employed.

## Discussion and Conclusions

The results of this investigation appear to be very clear in indicating that color as a code affects performance in a manner no different from any of the achromatic codes used, and like those codes it is consistent with the ten principles presented earlier. Sometimes color did appear to be associated with the best performance, but sometimes it was associated with the worst performance. It was most consistently associated with best performance under conditions requiring search for a target in a crowded display. That presumably, reflects the attensity of color as used in these experiments. However, the color symbols could have been made more or less attense by manipulation of brightness and size and a change of the number of colors employed. That it is possible to do that does not suggest that color provides a unique quality for coding displays. The same can be done with any code set. The only more or less unique property of color is its amenability to areal coding as in maps. Even here the same can be done with brightness and flicker or simply by bordering an area with heavy lines.

When then should color be used in coding displays? The most effective applications would seem to be:

1. In designating a specific target in a crowded display.

2. In demarcating an area of a display.

3. For warning signals or commands which have a limited number of possible alternatives.

4. For classifying or grouping data where the number of classifications are small.

In all four cases the use of color should be made carefully with attention to the principles of coding described earlier. Furthermore, it should not be understood that color is uniquely better for any of those four applications than other codes because <u>any</u> code set can be used in the same way with the exception of areal coding.

## PART II

This section of the report describes the details of the three new experiments which were summarized in Part I. The purpose of these experiments was to compare the effects of coding variables on performance at the same relatively simple tasks when those tasks were combined in a noncontingent manner over a series of discrete trials and when they were combined in an integrated manner in the context of a complex continuous task.

### EXPERIMENT 1: COMBINED TASK I

This experiment was designed to investigate the relative effects of color coding in a multiple display-multiple task situation. Subjects were required to monitor a display console and to respond as requested to one of three different tasks: choice reaction, search and locate, and identification-memory. The requests to respond to each of the different tasks occurred on randomly selected trials. The stimuli used in the displays were selected from a single code (letters, digits, shapes, colors) or were selected from one of the six pairwise combinations of those four codes sets (e.g., letters and digits, or shapes and colored dots).

The subjects used in the previously-reported single-task experiments (cf., Christ and Corso, 1975) were also used in Experiment 1. Consequently, the subjects were highly practiced in each of the tasks and were very familiar with each type of stimulus configuration. In addition it was possible to compare performance directly in the single task and in the multiple task context while task and stimulus conditions were held constant.

#### Method

##### Apparatus

The apparatus used for Experiment 1 consisted of a multiple display-multiple task system designed specifically for this research program. Since this system has been described in detail in an earlier report (Christ, Stevens, and Stevens, 1974; Christ and Corso, 1975), only a brief description will be given here.

The overall configuration of the displays and controls is illustrated in Figure 3 which shows a photographic view of the apparatus from over the left shoulder of a subject. Figure 4 shows a more detailed photograph of the display and control consoles.

Displays. The displays for Experiment 1 were constructed using IEE Series 00100 single plane rear-projection readouts. Each IEE unit consisted of 12 projection lamps and 12 film messages. When one of the lamps was lighted it illuminated the corresponding film message, focused it through a lens system, and back-projected it to a non-glare viewing screen.

Figure 5 illustrates the types of films used with these display units. Films C through H were designed so that any one of four target codes (letters, digits, familiar geometric shapes, and colored dots) or any one of the six two-way combinations of these four codes could be used in a given experimental session. The colored dots were produced by placing Roscolene color filters in front of the solid circles shown on Films F, G, and H. The type style of the single letters and single digits used in Films C through H was Alternate Gothic #3. The projected height of the single letters and digits was 0.94 inch (2.39 cm) and the projected diameter of the dots was 0.50 inch (1.27 cm). Film I was used only in the identification-memory task and then only the message "FULL", was used. The type style of the words shown in Film I was also Alternate Gothic #3, but the projected height of these letters was only 0.185 inch (0.47 cm). Only one message per readout was illuminated at any given time and all messages were projected to the center of the viewing screen for that readout.

Figure 3: A photographic view of the apparatus as seen over the left shoulder of a subject.

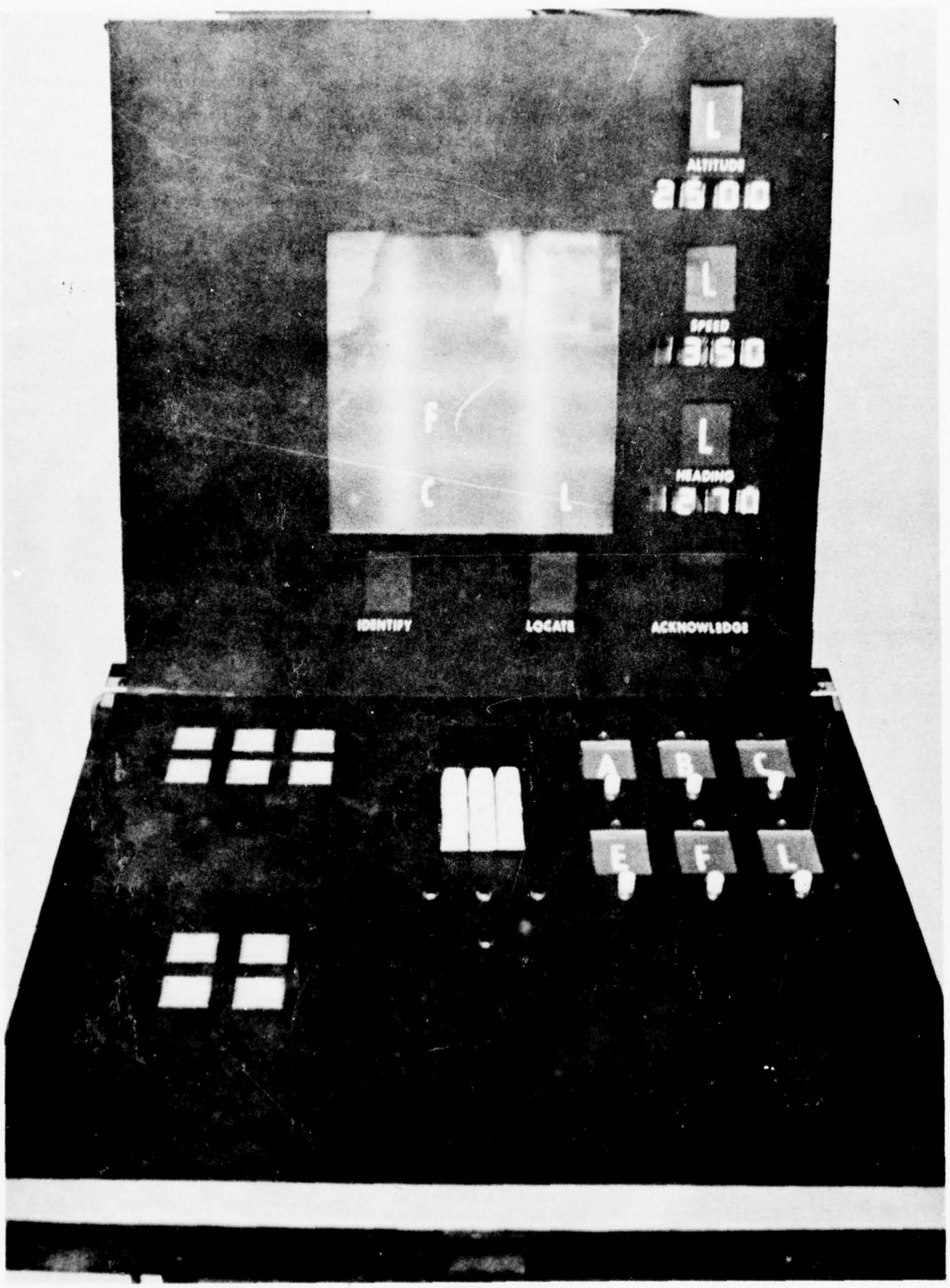


Figure 4: A photographic view of the display and control consoles.

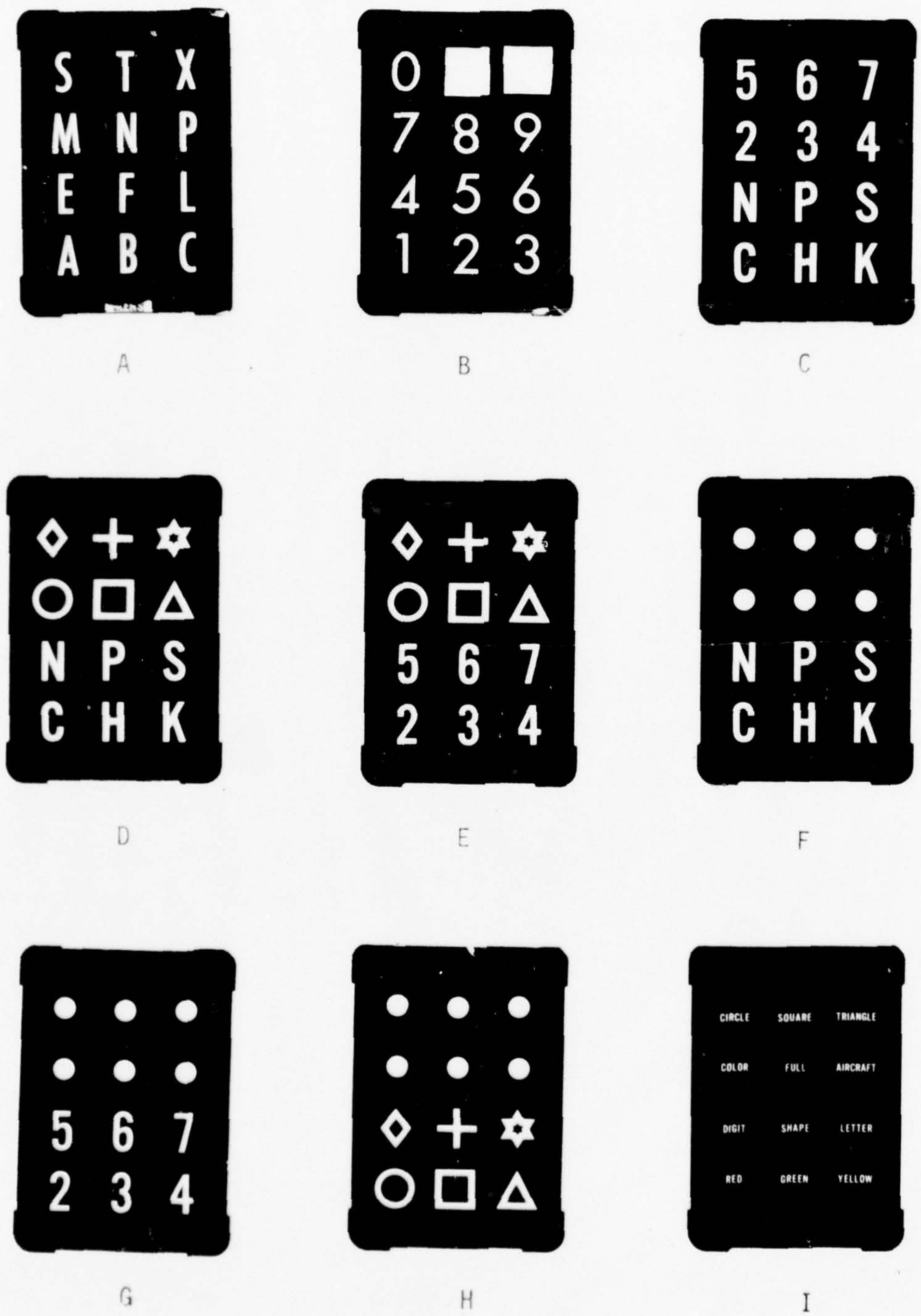


Figure 5: Photographs of nine films used with the single plane readouts.

The six color filters used to produce the color coding dimension gave colors designated as purple, blue, green, yellow, orange, and red. The manufacturer's numbers for these filters were 843, 850, 871, 806, 817, and 821, respectively. The total transmission of these filters, as a percent of an incandescent light source, is 18, 30, 31, 88, 56, and 16, respectively. These transmission measurements were provided by the manufacturer and based on measurements taken with a General Electric photometer. The average brightness of the alphanumeric messages in an IEE readout, using standard lamp No. 1820, was 8.0 foot-lamberts (27.4 cd/$m^2$)* at a rated voltage of 18 volts. This value was derived using conversion tables provided by Industrial Electronic Engineers, Inc. Combining the transmission characteristics of the color filters and the rated brightness of the normal white messages, it may be seen that the average brightness computed over the six colors was not equal to the average brightness of the achromatic stimuli. Specifically, the average brightness of the color symbols was 3.19 foot-lamberts (10.9 cd/$m^2$) at a rated voltage of 18 volts. No attempt was made to equate the brightnesses of the six different colors; neutral density filters were not available when the research was initiated and there were no facilities for directly and accurately measuring the actual brightness obtained. Furthermore, data previously reported by Christ and Corso (1975) showed that variations in brightness in the range under consideration do not affect the relative effectiveness of color coding.

The display console used for Experiment 1 was designed to hold one large multiple stimulus display and three smaller single stimulus displays. The large multiple stimulus display is shown in Figure 4 in the center of the display console. This display consisted of 16 IEE single plane readouts arranged in a four x four matrix. This matrix display was mounted behind a common viewing

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* candela per square meter

screen. While all six of the smaller peripheral displays shown in Figure 4 were visible to the subjects in this series of experiments, only those three at the bottom of the display console were used and then, no more than one at a time. The small display labeled ACKNOWLEDGE was used to request or signal a choice reaction task, the display labeled LOCATE was used to request a search and locate task and the display labeled IDENTIFY was used to signal an identification-memory task.

With the exception of the IDENTIFY display, the same film was used in all of the IEE readouts used in Experiment 1. The design of the films made it possible for all projected messages to be coded identically (single-code display) or for the messages to be coded by two coding variables (dual-code display). Figure 6 presents examples of these two types of display conditions as they applied to the matrix display. It may be seen that the displays labeled B and D in Figure 6 are single-code shape and single-code letter displays, respectively. The displays labeled A and C in Figure 6 are dual-code digit-shape and dual-code letter-color displays, respectively. The messages in each display were lighted and shown against a dark gray background. Color filters were used in conjunction with the dots shown in the display labeled C in the figure.

Controls. The control console shown in Figures 3 and 4 consisted of four clusters of buttons. Each cluster of buttons was designed to receive a subject's responses for a different task. The six IEE units and associated buttons in the upper right corner of the control console shown in Figure 4 were used to identify targets in the choice reaction task and identification-memory task. A standard arrangement of buttons was used for each of the four types of stimulus codes. In single-code displays the standard arrangement for letters was from left to right, top to bottom row, C, H, K, N, P, S; the arrangement for digits was 2, 3, 4, 5, 6, 7; the arrangement for familiar geometric shapes was circle,

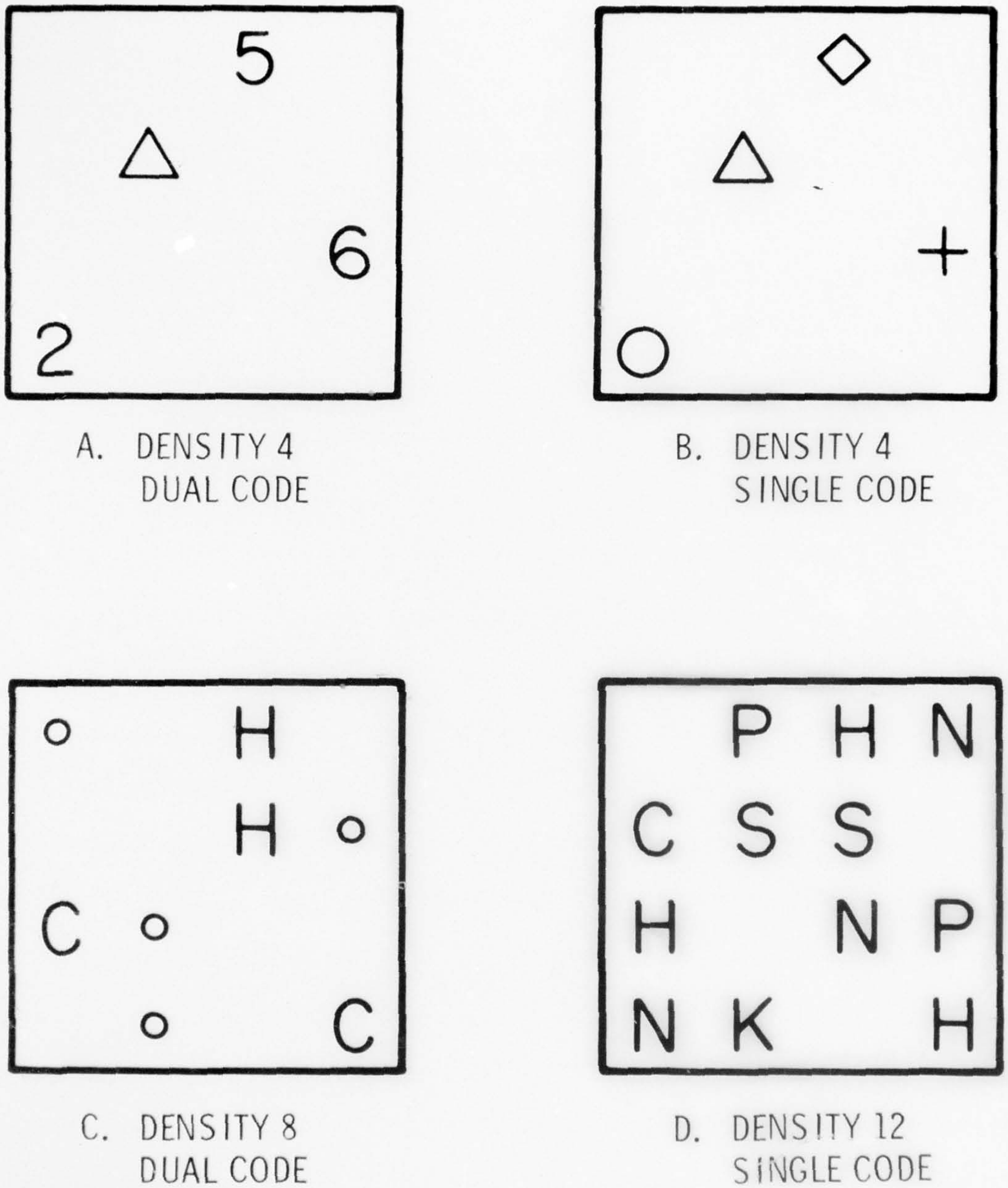


Figure 6: Examples of the types of matrix displays used in Experiments 1 and 2. The small circle in C represents the location of colored dots in the display.

square, triangle, diamond, cross, star; for colored dots it was purple, blue, green, yellow, orange, red. These particular values within each code and the sequencing of values over the six response units were chosen in an attempt to approximate equal sitmulus-response compatibility across codes. In the dual-code choice reaction task and identification-memory task the first three values of one target code were combined with the second three values of another target code. For example, in the letter-digit dual-code condition the arrangement of response units was either 2, 3, 4, N, P, S or C, H, K, 5, 6, 7.

The search and locate response units consist of four momentary contact buttons arranged in a two x two matrix. This response unit may be seen in the lower left corner of the control console shown in Figure 4. The subject used this response unit to specify the location (quadrant) of a target in the matrix display.

The only other response button used in Experiment 1 was the lowest button of the set of four buttons shown centered in the control console in Figure 4. This button was used to terminate the trial in the identification-memory task. The numeric keyboard shown in Figure 4 and the three buttons in the row immediately below the keyboard were removed from the control console and that entire area was covered by an aluminum panel. The six buttons in the upper left of the control console were exposed to the subject but they were never used.

Programming

The entire system shown in Figures 3 and 4 was interfaced with a PDP8/e minicomputer. The software developed for this computer controlled all programmable sequences of display events. The experimental program and up to 100 stimulus sequences of 30 trials each were written onto one auxiliary magnetic tape (Dectape) and the results were stored on a second tape.

## Subjects

The eight male subjects used in Experiment 1 were those who had participated in the previously reported single-task experiments (cf., Experiments 1, 3-10, Christ and Corso, 1975). The subjects were paid a fixed sum per experimental session for their participation and were also given a monetary incentive based upon their performance. All subjects were between the ages of 19 and 24, and they were all right-handed. In addition, subjects all had a visual acuity of at least 20/15 in each eye as measured with the Snellen chart and normal color vision in each eye as determined by the American Optical H-R-R Pseudoisochromatic Plates.

The eight subjects were assigned to one of two groups primarily on the basis of scheduling convenience. In general, subjects in Group A ran in sessions scheduled on Monday through Thursday. Subjects in Group B ran in sessions scheduled for Wednesday through Saturday. This scheduling was used to enable optimal use of the facilities and experimenter's time, and to allow at least a minimum degree of counterbalancing of conditions over successive sessions.

## Procedure

Each trial of Experiment 1 began with the onset of the matrix display followed after 500 ms by the onset of one of the three small task request displays. Over a series of thirty trials, the matrix contained four stimuli on 15 trials and eight or twelve stimuli on the other 15 trials. The single task request display used on a given trial presented only one stimulus. On choice reaction trials the ACKNOWLEDGE display presented a target stimulus which the subject had to identify as rapidly as possible. On these choice reaction trials the matrix presented either four or eight stimuli, or four or twelve stimuli, depending upon the particular sequence of 30 trials. In all cases, the stimuli presented in the matrix were independent of the target shown in the ACKNOWLEDGE display and these matrix stimuli were irrelevant to the identifying response which was requested.

On search and locate trials the LOCATE display presented a target stimulus which was also contained in the matrix display. On these trials the matrix contained either four or twelve stimuli. The subject was instructed to locate the target stimulus in the matrix and to identify its location by quadrant as rapidly as possible. Identification-memory trials were initiated by the presentation of the message "FULL" in the IDENTIFY display. This message served as a signal for the subject to report as many stimuli from the matrix as he could. The matrix always contained either four or eight stimuli on identification-memory trials.

The matrix display and task request display remained on together for 1500 ms or until the subject made a response, whichever occurred first. If the trial were a choice reaction trial or search and locate trial the subject had a maximum of 1500 ms within which to respond after the target was presented in the task request display. If no response were made during this interval, the trial was automatically terminated. If the trial were an identification-memory trial the subject had a maximum of 1500 ms after the request was made to encode the stimuli in the matrix, and then he had a maximum of 4000 or 8000 ms to report the stimuli. The matrix and task request displays were terminated after 1500 ms or when the subject made his first response, whichever occurred first. The multiple target report interval was determined by the number of stimuli in the matrix; 1000 ms was allowed for each of the four or eight displayed stimuli. If the maximum allowable response interval lapsed before the subject completed his report of the stimuli, the trial was automatically terminated. If the subject reported all the stimuli he could remember before the maximum allowable response interval lapsed, he had the option of manually terminating the trial by pushing a "terminate" button or simply waiting for the response interval to terminate automatically.

There was a 100 ms interval between the termination of one trial (whether that termination was automatic or manual) and the onset of the matrix for the next trial. There were always 30 trials in each block or sequence of trials. These 30 trials were equally divided among the three tasks. Hence, each 30-trial block had ten choice reaction trials, ten search and locate trials, and ten identification-memory trials.

The specific sequence of 30 matrix displays and the targets presented in the ACKNOWLEDGE and LOCATE task request displays were generated by combining preprogrammed segments from the sequences of trials used in the previously reported single task experiments. Specifically, each Experiment 1 sequence consisted of ten trials from a single task locate sequence of trials, ten trials from a single task identify sequence of trials, and ten trials from a single task choice reaction sequence of trials.

The density of stimuli used in matrix displays for search and locate trials was equally divided between four and twelve. For identification-memory trials the density of stimuli in the matrix display was equally divided between four and eight. Since the old single task choice reaction sequences did not include matrix displays, the matrices that were assigned to the choice reaction trials in Experiment 1 came from either the single task search and locate sequences or the single task identification-memory sequences. The actual sequence of tasks and matrix densities was randomized over the thirty trials in each block of trials with the restriction that no task and no matrix density was allowed to follow itself more than twice in a row.

Five blocks of 30 trials constituted a display condition. The first block of 30 trials in each display condition was for practice. The next four blocks of trials were experimental trials. There were about 30 seconds between successive blocks within a display condition.

There were three display conditions per experimental session. The first display condition was always a single-code display condition in which all stimuli were sampled from a single stimulus code . The second and third display condition in each session were dual-code display conditions in which one-half of the stimuli in each matrix was sampled at random from one stimulus coding dimension and the other one-half from another stimulus coding dimension (e.g., one-half of the stimuli in the matrix could be letters and the other half could be digits). The stimuli actually used in the dual-code matrices for the search and locate trials and for one-half of the choice reaction trials were sampled from the entire set of six stimuli in each relevant coding dimension. The stimuli used in the dual-code matrices for the identification-memory trials and in the other one-half of the choice reaction trials were sampled from only the first three or the last three stimuli in each coding dimension. In the latter case, all of the stimuli which appeared in the dual-code matrix had a corresponding response button.

One of the two dual-code display conditions was a compatible dual-code display condition and the other was an incompatible dual-code display condition. In the compatible display condition the same six stimuli were possible targets in all three tasks. For example, in the compatible dual-code display condition, C, H, K, 5, 6, and 7 could be the six target alternatives for the search and locate and choice reaction tasks and they were the only stimuli which could occur in the matrix display for the identification-memory task. In the incompatible display conditions one set of six stimuli served as target alternatives in the search and locate task and a different set of six stimuli served as target alternatives in the choice reaction and identification-memory tasks. For example, in the incompatible dual-code display condition, if C, H, K, 5, 6, and 7 were the six target alternatives for the search and locate task, then 2, 3, 4, N, P, and S were possible targets for the choice reaction and identification-memory tasks.

While the five blocks of 30 trials which comprise the single-code display condition always came first in an experimental session, the compatible and incompatible dual-code display conditions occurred equally often as the second and third display conditions over the six experimental sessions. There was a brief rest interval of about two minutes between successive display conditions within each session.

Each subject served in seven sessions. The first session was a practice session. That session used either colored dots or digits in the single-code display condition and colored dots and digits in the dual-code display conditions. The practice session was identical in all respects to the experimental sessions except that the matrix and task request displays had a maximum joint duration of 2000 ms rather than the 1500 ms used in experimental sessions. Sessions 2 through 7 were experimental sessions. Each subject had each of two single-code display conditions once and each of the other two single-code display conditions twice over the six experimental sessions. Only the first encounter with each of the four single-code displays was scored and analyzed. One-half of the subjects went through the six dual-code display conditions in one order (digit-shape, shape-color, letter-color, digit-color, letter-shape, letter-digit) and the other subjects went through these dual-code display conditions in the reverse order. For each dual-code condition four of the subjects had one combination of codes (e.g., C, H, K, 5, 6 and 7) and four had the other combination (e.g., 2, 3, 4, N, P, and S).

## Results

The results of Experiment 1 were analyzed separately for each task. Within tasks the absolute levels of performance were analyzed for each display condition. In addition, the results for the color code condition were evaluated relative to each of the achromatic code conditions. Finally, the performance of each subject for each task in this combined task situation was compared to his performance in the comparable single task condition previously reported (Christ and Corso, 1975).

Major segments of the data for one subject were lost during storage on and retrieval from the minicomputer magnetic tape system. Consequently, the following results are based on the performance of only seven subjects.

### Choice Reaction Task

Accuracy. The number of accurate choice reaction responses and the number of commission errors made by each subject were determined over the ten choice reaction trials in each block of trials and then those data were collapsed over the four experimental blocks of trials within each display condition.

Examination of these data showed that the subjects were very accurate in their responding: 93.6 percent of all single-code trials were responded to correctly and 94.5 and 96.4 percent of the compatible and incompatible dual-code trials were correct. The corresponding percentage of trials on which there were incorrect responses was 3.0, 2.3, and 1.2. Combining these two measures it may be seen that even though the subjects had only 1500 ms within which to respond, they almost always did respond. Errors of omission occurred on only 3.4, 3.2, and 2.4 percent of the single-code, the dual-code compatible, and the dual-code incompatible trials, respectively.

Since accuracy was so high there is no need to report on the more detailed analyses of the data. That is, even when analyses of variance showed significant treatment effects on the accuracy data, those effects were too small to be of any practical value.

Choice reaction time. The mean choice reaction time for correct responses was determined for each subject within each block of ten trials. Those data were then pooled over the four experimental blocks within each display condition to yield the raw data used in analyses of variance. An analysis of the mean choice response times in the single-code display condition showed that the only significant effect was due to density, $F(1, 6) = 11.4$, $p < .05$. An examination of the data showed that response time was shorter on the higher density trials than on the low density trials (895 and 923 ms, respectively).

Since the matrix display was unrelated to the requirements of the choice reaction task a question arises concerning the relation between choice response time and the density of the matrix display. That is, even though the matrix display was presented 500 ms before the request for a choice reaction and even though the subject may have attended to the matrix display, all the information the subject needed for a correct response was in the ACKNOWLEDGE display. To examine the effect of the matrix display on choice reactions the performance of each subject in Experiment 1 was compared to his performance in the previously reported single task choice reaction condition (cf., Experiment 8 of Christ and Corso, 1975). All subjects had served in Experiment 8 approximately one month prior to their participation in the present experiment. Except for the presence of the irrelevant matrix display and the uncertainty associated with when the choice reaction task would be requested, the choice reaction task was identical in the two experiments.

An analysis of performance levels in the single-task and the combined-task experiments showed significant effects due to experiment: $F(1, 6) = 51.63$, $p < .01$, for the Low Density combined task vs. single task comparison and

$F(1, 6) = 36.6$, $p < .01$, for the High Density combined task vs. single task comparison. Overall average choice response time for Experiment 8 was 6.31 ms. The corresponding mean choice response times for Low and High Density conditions in the combined-task experiment were 923 and 895 ms, respectively. The differential magnitude of the comparative response times suggests that in addition to whatever the possible effect of task uncertainty, subjects were attending to and processing the contents of the matrix display prior to the presentation of a task request display. This interpretation is further supported by the significant effect of density on choice response time in the present experiment.

The mean choice response time in the dual-code display conditions was also used in an analysis of variance which showed that the only significant effect was due to the main effect of within-code combination. To facilitate an examination of within-code combination effect the data from the single-code and dual-code conditions were combined to yield an orthogonal design consisting of four levels of target code, four levels of background code, two levels of matrix display density, and two levels of target code compatibility. An analysis of variance of those data showed a significant interaction between target and background codes, $F(9, 54) = 3.19$, $p < .01$. The form of that interaction effect may be seen in Figure 7 which shows mean choice response time for each combination of target code and background code. Neuman-Kuels tests of all pairwise comparisons showed that the only significant differences were between the longest response time shown (952 ms to letter targets when the matrix contained letters and digits) and the two shortest response times shown (829 ms to letters in the letter-shape matrix condition and 829 ms to digits in the digit-color matrix condition).

Relative scores. Several analyses were performed on relative scores derived from the absolute choice response time data. The effectiveness of color coding

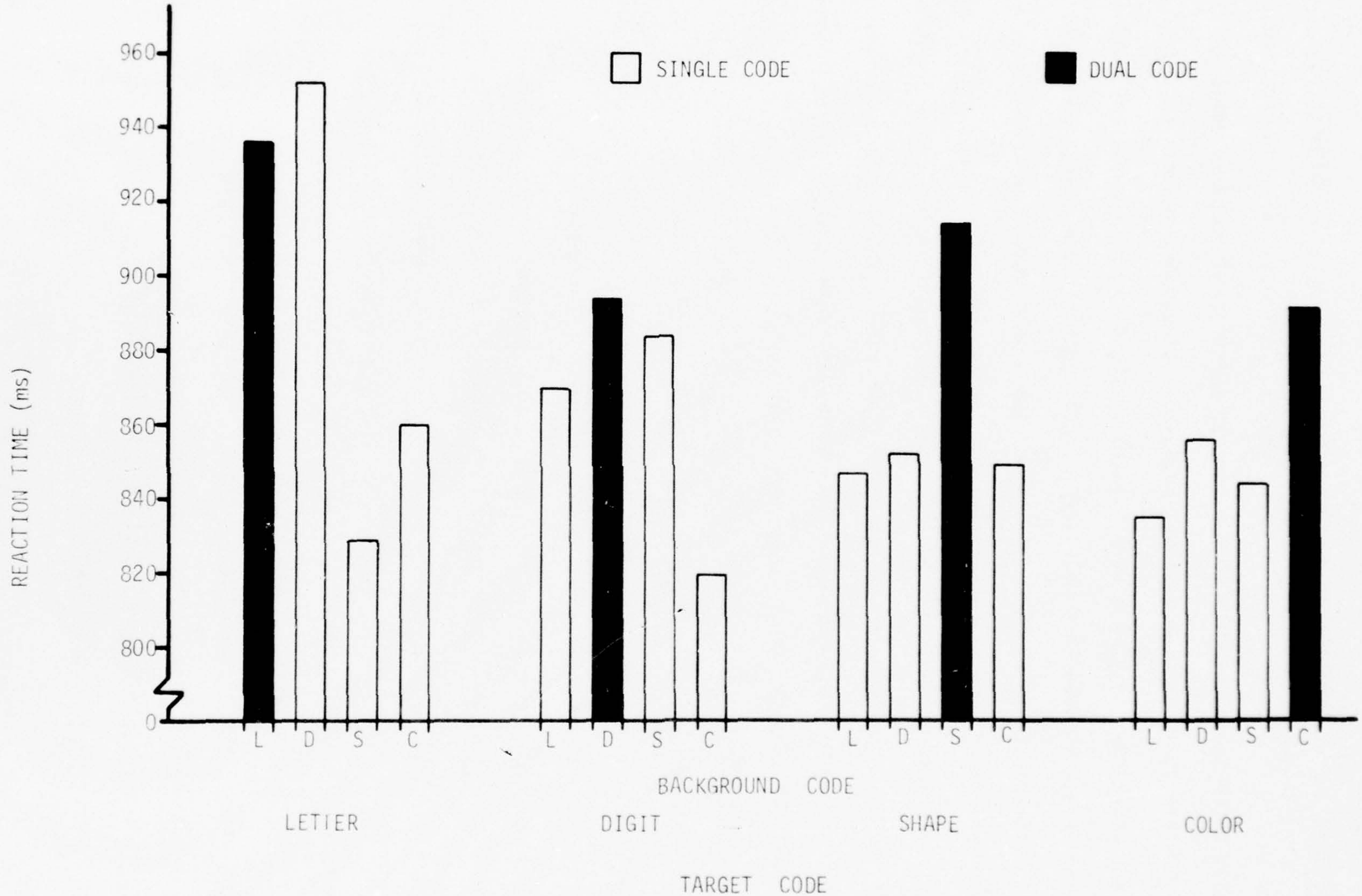


Figure 7. Choice reaction time in Experiment 1 as a function of target and background code sets.

in the single-code displays was analyzed relative to the three achromatic coding variables. Specifically, the difference between choice response time to color and to each achromatic code was divided by the choice response time in the achromatic code condition. Positive scores indicate an advantage for color; negative scores a disadvantage for color, both relative to a particular achromatic code. An analysis of these relative scores shows no significant effects due to any independent variable. Overall, choice response time to color was 2.2 percent shorter than to achromatic targets. That rather small gain for color coding seemed not to be due to a speed-accuracy trade-off since the least and most accurate target codes (color and digits, respectively) were both associated with the shortest response times.

In the dual-code conditions, an analysis was performed on the effectiveness of color-coded targets relative to each achromatic target code for constant background conditions. That analysis yielded no significant treatment effects. Overall, with background held constant, color target codes led to choice response times which were 2.5 percent shorter than response times obtained with achromatic targets.

Comparisons were also made between color and achromatic background stimuli for constant target conditions. An analysis of those data showed that the only significant effect was due to the code comparison variable, $\underline{F}(5, 30) = 2.88$, $\underline{p} < .01$. An examination of that main effect showed that the choice response time to achromatic targets is generally shorter if color codes are used as background stimuli in the matrix display than if some other achromatic code is used as background stimuli. The overall relative effectiveness of color codes as background, or the absence of an interference effect due to color background stimuli, was 2.8 percent. A test of all pairwise comparisons showed that the only significant comparison was the most extreme pair of difference scores:

letter targets when color and digit backgrounds were compared (+9.1%) and letter targets when color and shape backgrounds were compared (-4.0%).

Another set of relative difference scores was determined between choice response time in the single-code display condition and choice response time in the comparable dual-code display conditions. For these difference scores a positive number indicated an advantage for dual-code display, negative scores a disadvantage for dual-code display, both relative to single-code displays having the same target code. An analysis of variance of these difference scores yielded no significant treatment effects. The overall effect, however, showed an advantage for dual-code displays over single-code displays; choice response times were 5.0 percent shorter with two stimulus codes in the matrix display than one. An alternative interpretation of that overall difference score is that there is an advantage for two response codes (with three alternatives in each code) over one response code (with six alternatives).

<u>Search and Locate Task</u>

<u>Accuracy</u>. The number of accurate location responses made by each subject was determined over the ten search and locate trials in each block of 30 trials. Those data were then further collapsed over the four experimental blocks within each display condition. Examination of the data showed that performance was highly accurate. In the single-code display condition subjects were correct on 85.8 percent of all location trials, they made incorrect responses on only 6.0 percent of the trials, and they made no response on 8.2 percent of the trials. The accuracy of search and locate responses was also quite high in the dual-code display conditions. Overall, subjects were correct on 91.8 percent of the dual-code locate trials, errors of commission were made on 3.9 percent of the trials, and locate responses were not made, i.e. were omitted, on 4.3 percent of the trials. By comparison, these same subjects were correct on 92.1 percent of the single-code trials and 92.7 percent of the dual-code trials

in the single task locate condition previously reported (cf., Experiment 7 in Christ and Corso, 1975). Hence, even though there was uncertainty concerning when a location response would be required in the present experiment, and no such certainty excisted in the previously run single task condition, and even though there was only 1.5 seconds within which to respond in the present combined task situation compared to 4.0 seconds in the single task situation, the subjects were essentially equally accurate in both situations.

An analysis of variance of the location response accuracy data from the single-code display condition showed that the only significant effect was due to the Code x Density interaction, $\underline{F}(3, 18) = 3.24$, $\underline{p} < .05$. The range of scores involved in this interaction effect varied from 78.6 percent correct for 12 Density-letter displays to 91.4 percent correct for 4 Density-digit displays; this largest difference was the only pairwise comparison which was significant.

An analysis of variance of the percentage of correct search and locate trials for the dual-code display conditions of the present experiment showed that code combination was a significant main effect at the .01 level, $\underline{F}(5, 30) = 7.35$, and that the compatibility main effect, $\underline{F}(1, 6) = 12.50$, the density main effect, $\underline{F}(1, 6) = 7.98$, and the interaction of code combination and density, $\underline{F}(5, 30) = 3.14$ were all significant at the .05 level. Inspection of the data revealed that accuracy was greater in the incompatible condition than the compatible condition (94.2% vs. 89.3%). It was also determined that there was no code combination effect in the Density 4 matrix condition but that accuracy in the letter-digit combination was significantly less than in any of the other five combinations in the Density 12 matrix condition.

The form of the code combination main effect is illustrated in Figure 8 which shows percentage correct as a function of target code with background code as a parameter. For comparison, the accuracy of each single-code condition is

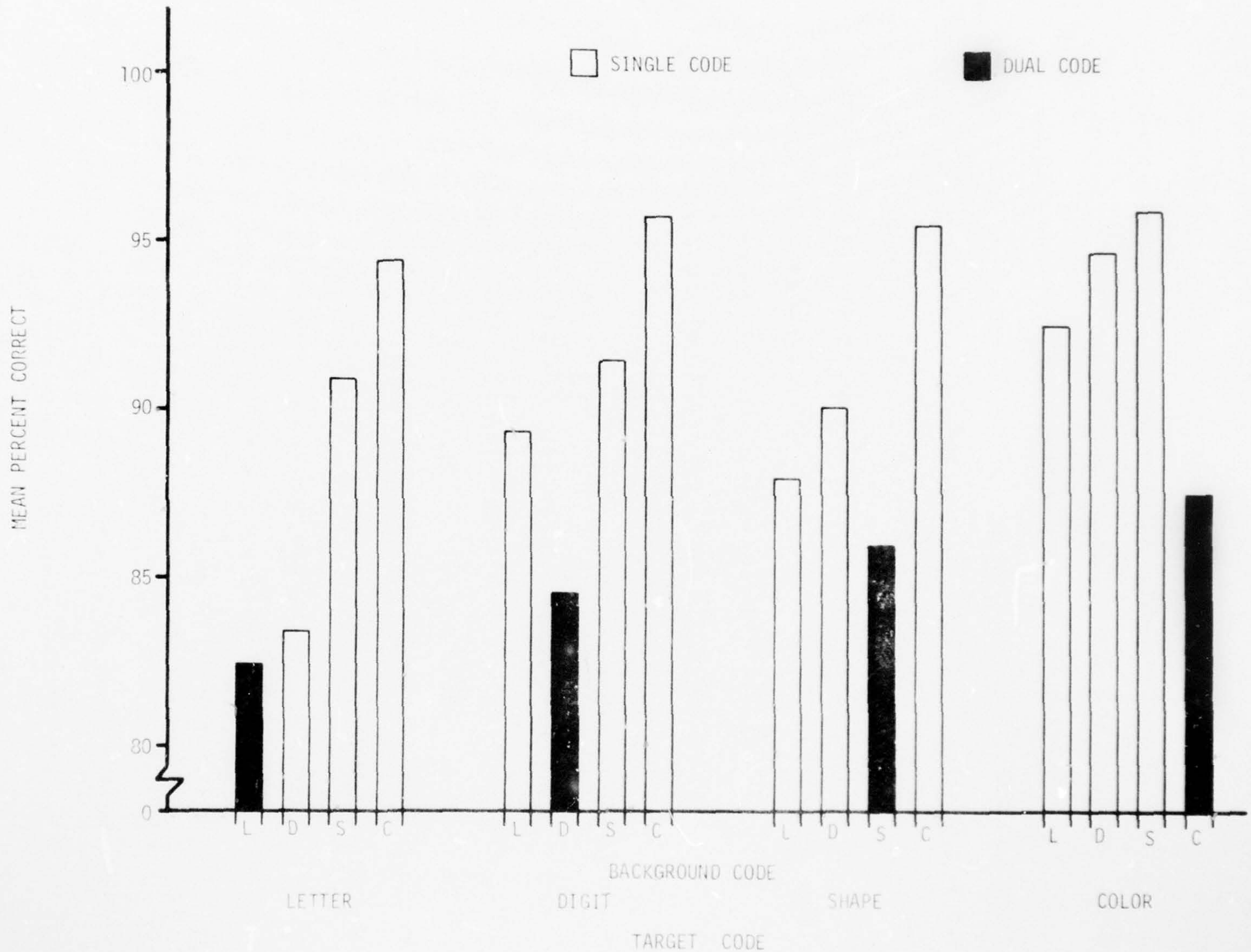


Figure 8. Percentage of correct search and locate responses in Experiment 1 as a function of target and background code sets.

also shown in the figure. An analysis of all pairwise comparisons showed that while there were no differences among background conditions in the dual-code displays which had digits or colors as targets, there were effects due to background conditions when letters or shapes were targets. Specifically, when a letter was the target the digit background condition led to lower levels of location response accuracy than the shape or color background conditions which did not differ from each other. When a shape was the target the letter background condition led to lower levels of accuracy than the color background condition but neither of these conditions were different from the digit background condition. An inspection of Figure 8 suggests that dual-code matrices which contained color stimuli either as a target code or as a background code led to more accurate search and locate responses than dual-code displays which did not include color. Furthermore, it may be seen that dual-code displays generally led to more accurate search and locate responses than single-code displays.

Search and locate time. The mean time required for all correct locate responses was determined over the ten search and locate trials in each block of trials and over the four blocks of trials within each display condition. An analysis of data from only the single-code display condition showed that the only significant effect was due to the density of the matrix, $F(1, 6) = 66.07$, $p < .01$. Mean search and locate time was shown to be shorter for the Density 4 displays than the Density 12 displays (937 and 1032 ms, respectively).

An analysis of the search and locate times from the dual-code display condition showed that the main effects of compatibility, $F(1, 6) = 9.16$, and code, $F(5, 30) = 3.28$, were both significant at the .05 level and that the main effects of density, $F(1, 6) = 926.74$, and within code combination, $F(1, 6) = 17.27$, were both significant at the .01 level. In addition, the analysis showed that three two-way interactions were significant: Code x Density,

$F(5, 30) = 2.80$, $p < .05$, Code x Code Combination, $F(5, 30) = 4.62$, $p < .01$, and Density x Code Combination, $F(1, 6) = 40.80$, $p < .01$. The main effect of compatibility conditions was due to overall longer search and locate times for the compatible than the incompatible condition (936 vs. 915 ms, respectively). The form of the relationships involving dual-code conditions, code combinations, and density effects are shown in Figure 9.

Figure 9 shows the mean search and locate time for each target code condition with the background code shown as a parameter. The solid bars in Figure 9 show comparable data from the single-code display condition. It may be seen that the two conditions which combined letters and digits (letter targets and digit background or vice versa) led to longer response times than the other five dual-code conditions which did not differ from one another. It may also be seen that dual-code displays which included color codes (either as targets or as background) generally were associated with shorter search and locate times than those conditions which did not include color. Finally, Figure 9 also illustrates that dual-code displays generally led to shorter response times than single-code displays.

The overall results found for search and locate time in the present combined task experiment are larger than those found in the single task experiment previously reported (cf., Experiment 7, Christ and Corso, 1975). The grand mean response times for the combined and the single tasks are 985 and 756 ms, respectively, for the single-code display condition and 926 and 708 ms, respectively, for the dual-code display condition. While there is a difference in overall response time for the combined and single task, it is important to note that this effect was uniform over target codes and other display variables.

Relative scores. In order to assess the relative effects of color coding and the relative effects of dual-code coding that were discussed in connection with Figure 9, several percent difference scores were derived from the absolute search and locate time data. The relative effects of single color codes in Experiment

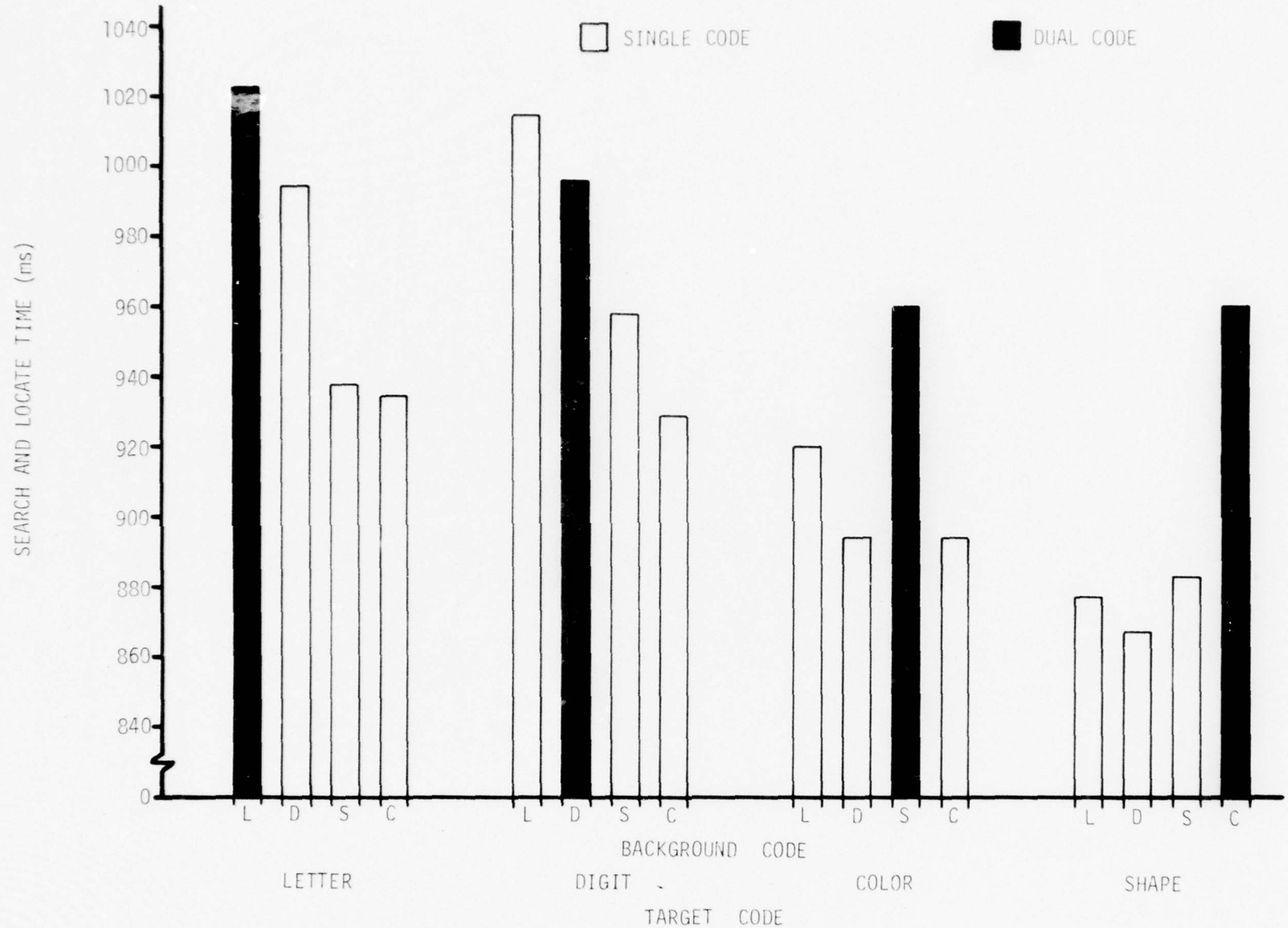


Figure 9. Search and locate time in Experiment 1 as a function of target and background code sets.

1 had no significant treatment effects. Overall, however, the search and locate times found for color targets were 6.6 percent shorter than for achromatic targets. The relative effects of color as a target code for constant background condition and as a background code for constant target conditions were determined for each subject in the dual-code conditions. An analysis of variance of the relative effects of color as a target showed that while there was an overall advantage for color relative to the achromatic code comparisons (7.5%) there was no differential effect over comparison codes. The only significant treatment effect was due to density, $F(1, 6) = 9.11$, $p < .05$. The relative effectiveness of color was shown to be greater in Density 12 than in Density 4 display (10.2% vs. 4.7%). There were no significant treatment effects for the data showing the relative effects of color as a background code. Overall, search and locate times to an achromatic target were 3.0 percent shorter if color was a background stimulus than if another achromatic code was the background stimulus.

The derived scores comparing performance in dual-code displays relative to single-code displays showed that there was an overall advantage for dual-code displays; 5.6 percent shorter search and locate times were obtained in dual-code displays than single-code displays. An analysis of variance of those derived scores showed, however, that the only significant treatment effect was due to compatibility condition, $F(1, 6) = 11.39$, $p < .05$. It was shown that the gain in performance obtained with dual-code displays over single-code displays was greater if target codes were incompatible rather than compatible (6.7% vs. 4.4%).

### Identification-Memory Task

Subject terminated stimulus and response intervals. The response records of each subject were examined to determine the extent to which the subject's first identification-memory response terminated the presentation of the displays.

The results show that subjects rarely responded before the displays had been presented for the maximum viewing time. On the other hand, with the exception of one subject who never used the trial-termination button, the subjects generally did terminate the identification-memory trials. Over the six subjects for whom there are data, 96.0 percent of all single-code display trials and 99.3 percent of all dual-code display trials were terminated before their maximum duration. This tendency for subjects to terminate the multiple target identification trials was equally evident for Density 4 and 8 matrix displays, and consequently, for four and eight-second response intervals.

Accuracy. The mean number of correct and incorrect (commission error) responses per identification-memory trial was determined separately for each subject as a function of display condition, code, and density. A quick look at those data clearly showed that the subjects were very accurate in their performance. Overall single-code display trials the subjects correctly identified an average of 5.34 targets (89.0%) and made an average of only .52 commission error per trial. Subjects were even more accurate in their recall and made fewer error responses on the dual-code trials. On those trials, subjects correctly identified 5.56 targets (92.7%) and they made only .37 error response per trial.

An analysis of variance of the number of correct responses on single-code trials showed that the only significant effect was due to matrix density, $F(1, 6) = 401.78$, $p < .01$. Subjects correctly identified 3.83 (95.8%) of the targets in Density 4 displays and 6.86 (85.8%) in Density 8 displays. An analysis of variance of the number of correct responses on the dual-code display trials showed that the following effects were all significant at the .01 level: density, $F(1, 6) = 596.91$, within code combination, $F(1, 6) = 21.64$, Code x Density, $F(5, 30) = 4.68$, Display Condition x Density, $F(1, 6) = 21.99$. In addition, the main effects of display condition, $F(1, 6) = 6.82$, and code, $F(5, 30) = 3.27$, were both significant at the .05 level.

An examination of these data for dual-code displays showed that the level of accuracy was essentially constant over all other conditions when the density was four; of the two targets presented for each code within the dual-code condition 1.96 targets (98.0%) were on the average correctly identified. When the display density was eight, the overall number of targets correctly identified per code increased to 3.59 (the percent correct decreased to 89.9%), but there was a differential effect due to levels of display compatibility, code combination, and code. In short, when Density was 8, accuracy was slightly less for the compatible code condition (89.3%) than the incompatible code condition (90.5%); less for the letter-digit code combination (85.0%) than for the other five code combinations (90.8%), but more for letter and digit target conditions with color or shape backgrounds and for shape targets with color background than for any other target-background code combination. The form of the effects of code conditions on accuracy may be seen in Figure 10. This figure shows the percentage of targets correctly identified as a function of dual-code target-background code combination. Also shown for comparison are the results obtained with the single-code displays.

The overall level of accuracy on multiple identification trials in the present experiment was substantially higher than was found for that task in the previously reported single task study (cf., Experiment 9, Christ and Corso, 1975). The overall number of commission errors per trials was shown to be smaller in the present study (.43 vs. .71) and accuracy increased for both Density 4 and Density 8 displays (89% vs. 80% and 93% vs. 85%, respectively). This overall increase in identification accuracy may have been due entirely to the increase in maximum encoding time from Experiment 9 to the present experiment

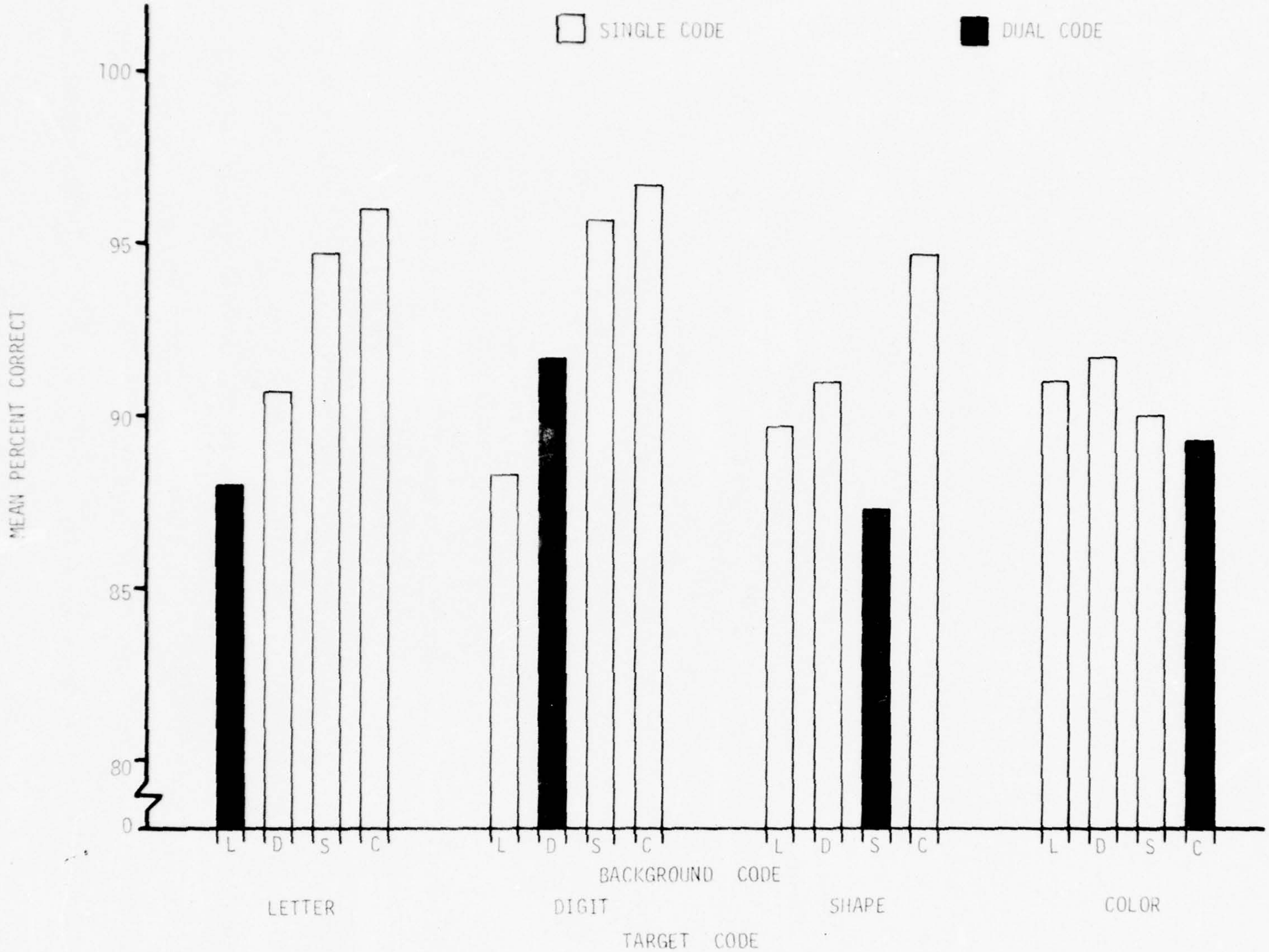


Figure 10. Percentage of targets correctly identified in the identification-memory task in Experiment 1 as a function of target and background code sets.

(400-800 ms in Experiment 9, 1500 -2000 ms in Experiment 1). Even so, it is worth noting that there is no differential effect of encoding time, task uncertainty (absent in Experiment 9 but present in Experiment 1), or practice on accuracy with different codes and code combinations.

Relative accuracy scores. The relative effectiveness of color as a target code in single-code display showed that color was neither more nor less effective than achromatic codes; the grand mean relative score was -.04 percent. An analysis of variance, however, showed that the specific achromatic code used in a comparison was a significant source of variance, $F(2, 12) = 4.06$, $p < .05$. Though statistically significant the relative scores were still not large; color led to slightly less accurate performance relative to digits (-2.97%), slightly more accurate performance relative to shapes (+2.21%), and to essentially the same level of accuracy relative to letters (+0.65%).

The comparisons between color target code and achromatic target codes while background codes were held constant showed that there was no overall gain or loss associated with using color (grand mean relative score was -0.84%).

Similarly, the data which compared color background stimuli to an achromatic background for some other constant achromatic target code showed only a very small (+3.86%) effect associated with using color. Finally, the percentage difference score which reflects the effects of display format showed that the accuracy of identification-memory responses was only slightly higher (+3.36%) for dual-code displays relative to single-code displays. Analyses of variance of these latter three sets of relative accuracy scores yielded some significant treatment effects but the range of scores involved was generally quite small and not of practical significance.

Order and organization of responses. The series of identification-memory responses made by each subject in the dual-code display conditions were examined to discover what, if any, differential organizational tendencies there might be as a result of target code combinations. Since the subject could report either one of the two target code sets first, one measure of response organization was the frequency of times the subjects' first response was for a target from one or the other target code conditions. Those data were determined over the five trials of each level of density as a function of the six target code combinations and the two levels of code compatibility. An analysis of variance showed that the only significant effects were due to density, $\underline{F}(1, 6) = 7.13$; Code x Density, $\underline{F}(5, 30) = 3.16$; Code Compatibility x Code, $\underline{F}(5, 30) = 2.92$; and Code Compatibility x Code x Density, $\underline{F}(5, 30) = 3.18$, all at $\underline{p} < .05$.

An examination of the data for the first target code reported showed that when the density of the display was four targets, two from each code within the code combinations, there was a strong effect due to code: letters tended to be reported before digits on 67 percent of the trials but shapes and colors tended to be reported before letters (62% and 58% of the time, respectively) and before digits (68% of the time in each case). Shapes and colors when combined tended to be reported first equally often (54% and 46%, respectively). When the density of the display was increased to eight targets, the differential tendency to report one of the codes before the other was no longer apparent. Now, except for the shape-color combination where shapes tended to be reported first (on 63% of the trials), the two target codes tended to be reported first equally often. Except for some relatively small and nonsystematic deviations, the same effects of density and code combinations on first report data were found for both conditions of display compatibility.

Another measure of response organization in the dual-code display condition was the number of responses made in one target code before the subject shifted his responses to those of the second target code, i.e., the length of the initial run of responses. Those data were weighted by the proportion of times each target code was reported first. The weighted first run length data were analyzed as a function of code combination, density, and code compatibility. It was shown that the only significant effects were due to code combination, $\underline{F}(5, 30) = 2.74$, $\underline{p} < .05$; and density, $\underline{F}(1, 6) = 147.67$, $\underline{p} < .01$. The mean first run length was 1.98 responses when the display density was four stimuli and 3.58 responses when the display density was eight stimuli. While there was relatively little variation in initial response run length when the density of the display was four stimuli, there was an effect due to target code combination when density was eight; at Density 8 the mean initial run length was 2.8 responses for the letter-digit combination and 3.7 responses for the other five target code combinations.

Overall, these finding for response organization are not consistent with the results obtained in the previously reported single task identification experiment nor are they particularly useful in explaining the relative effectiveness of color. The previously reported single task results showed that subjects tended to report achromatic targets before chromatic targets, the reverse was found here and then only for the low density displays which yielded no differences in accuracy or commission error as a function of code combinations. The length of the initial run of responses was consistent between the two experiments but these data merely show that the subjects tend to report all the items from one code before switching to the other code.

Response time. Figure 11 shows the distribution of response times for each single-code display condition and for each code combination within the dual-code display conditions. Two different response time measures are shown in the figure: the mean time for the first identification-memory response on a given trial and the mean response time of all correct identification-memory responses.

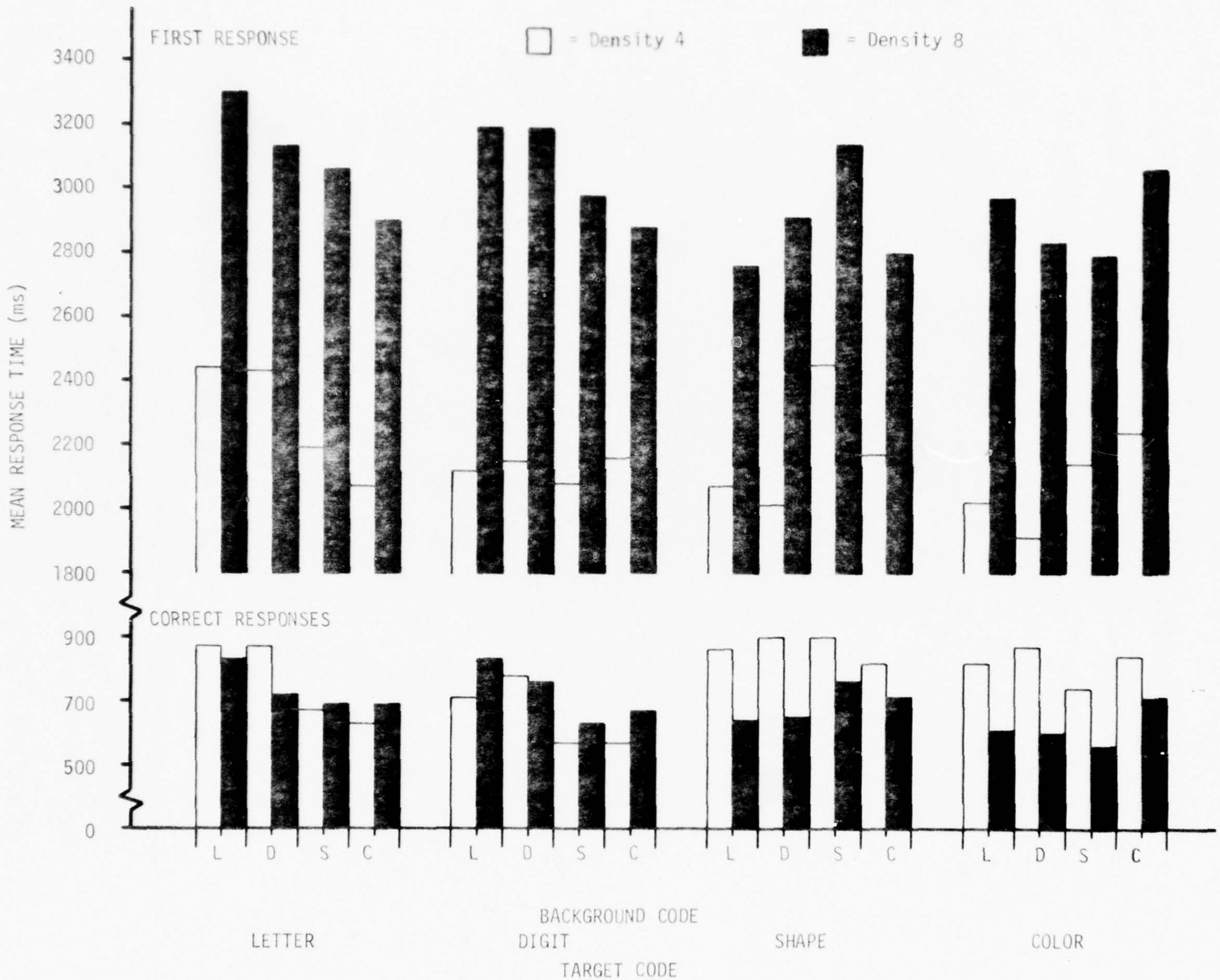


Figure 11. First response time and overall mean response time in the identification-memory task in Experiment 1 as a function of display density and target and background code sets.

The latter response time measure was determined by averaging over the first identification-memory response if it were correct (as it almost always was) and all relevant interresponse times in the subsequent series of correct identification-memory responses. These two response time measures were determined over the ten identification-memory trials in each block of thirty trials and then pooled over the four blocks of trials within each display condition.

An analysis of first response times for the single-code display condition showed that the only significant effects were due to density, $F(1, 6) = 70.80$, and Density x Code Combination, $F(3, 18) = 3.69$, both at $p < .01$. An examination of the data showed that the first response required 2319 ms when there were four targets in the matrix and 3175 ms when there were eight targets. The Density x Code interaction effect was due to a tendency for the reports of digits and colors to begin more quickly than the reports of letters and shapes when the display contained four targets; when the display contained eight targets the only pairwise difference which was significant was between first response time to letters and to colors.

An analysis of the mean first response time for dual-code displays showed that significant effects were due to code combinations $F(5, 30) = 2.75$, $p < .01$. The density main effect was due to a longer first response time when density was eight (2934 ms) than when density was four (2112 ms). The main effect of code combination of first response time was shown to be due to a longer first response time for the letter-digit combination (2718 ms) than for any of the other five code combinations (2488 ms).

Comparison of first response time data from this combined task experiment and the previously reported single task experiment showed a difference in favor of the single tasks. The overall first response time for single-code identification-memory trials increased from 2096 in Experiment 9 to 2747 ms in the present combined task experiment; the corresponding increase for dual-code identification-memory trials was from 1939 ms to 2444 ms. Much of the difference in first response time between the two experiments may be due to the exposure time factor. In the isolated task experiment the duration of the stimulus array was 400 and 800 ms for Density 4 and 8 displays, respectively. In Experiment 1 exposure time was constant at 1500 ms. Subtracting the stimulus duration from the latency of the first responses yields an average time for beginning a recall in the isolated task experiment of 1309 ms and 1501 ms for Density 4 and 8 displays, respectively. The corresponding mean times for beginning a recall in Combined Task I were about 700 and 1500 ms. Hence, due to the shorter exposure times used in the isolated task experiment, the subjects may have used the period between the termination of the display and their first response for both continuing their encoding of the display and for organizing their responses. By contrast, the longer exposure times used in Combined Task I may have allowed the subject to completely encode the input (especially for Density 4 displays); the subsequent time required for the first report was then a function only of how long it took to organize their responses. The interpretation given here for the difference between Experiments 9 and Combined Task I should also take note of the increase in overall accuracy of responding and the increase in practice between the two experiments.

An analysis of variance was performed on the mean correct response times for single-code displays. This analysis showed that density, $F(1, 6) = 10.04$, and code, $F(3, 18) = 3.77$, were significant at the .05 level and that Code x Density, $F(3, 18) = 5.39$, was significant at the .01 level. Generally, correct response times were shorter for Density 8 displays than for Density 4 displays (764 ms vs. 846 ms). The Code and Code x Density effects were shown to be due to the longer response times for letters and shapes than for digits and colors;

response times for digits were shorter than response times to the other codes when density was four but only the two extreme response times (letters and colors) were significantly different when density was eight. These results are illustrated in Figure 11. A comparison of the single-task response times between Combined Task I and the previously reported single task experiment yielded very similar functions except for the relatively long response times to shapes and colors in the Density 4 condition of Experiment 1.

An analysis of variance of the correct response times for dual-task display trials showed that code combination, $\underline{F}(5, 30) = 4.55$, Density, $\underline{F}(1, 6) = 29.38$, and Code Combination x Density, $\underline{F}(5, 30) = 3.77$, were all significant at the .01 level. These effects are illustrated in Figure 11.

It may be seen in Figure 11 that for the dual-code conditions with letter or digit targets there is generally only a small difference due to density and then, except for the letter target-digit background combination, the correct response times are shorter for Density 4 displays than Density 8 displays. In contrast, the dual-code conditions with shape or color targets show a large difference in correct response times due to density and then the response times are shorter for Density 8 displays than Density 4 displays. Pooled over the two targets within each code combination there is a very large density effect for all code combinations except the letter-digit combination. Correct response times were relatively constant around 752 ms for Density 4 displays but for Density 8 displays the mean correct reaction time for the letter-digit combination (744 ms) was much longer than for the other five combinations (645 ms). The mean correct response times from the previously reported single task experiment showed no effects due to density and the code combination effect was essentially identical to the one just described for the Density 8 condition in Experiment 1.

Relative response time scores. The relative effectiveness of single color codes on correct response times was determined for each subject as a function of achromatic codes and density. When those data were used in an analysis of variance it was shown that Density, $F(1, 6) = 7.55$ and Density x Code, $F(2, 12) = 5.92$, were both significant at the .05 level. Pairwise comparisons showed that the most extreme percent difference scores were significantly different from each other and from all other scores. The response times to colors were 7.5 percent shorter relative to letters when density was eight; the other percent difference scores (mean equal to +5.75) did not differ from each other.

Color target codes were shown to be ineffective relative to achromatic target codes when background code was held constant for the dual-display condition. The overall percent difference score was -2.85 percent. An analysis of variance of these data showed that the only significant effect was due to the interactions of the comparison achromatic code and code compatibility, $F(5, 30) = 3.43$, $p < .05$. An examination of the interaction failed to show any systematic effects. The range of percent difference scores went from a loss of -20.6 percent to a gain of 10.7 percent.

The comparison between color background code and achromatic background code for constant target code showed no overall gain or loss associated with color coding. The percent difference scores for color background coding went from a loss of -33.7 percent to a gain of +31.5 percent; the overall mean was +.3 percent. An analysis of variance showed no significant treatment effects.

A comparison between single-code displays and dual-code displays showed an overall advantage for the dual-code displays (+11.7%) on correct response times. There was, however, a considerable amount of variability in the data. At one extreme, digits are reported less quickly in Density 8 dual-code digit-letter displays than in Density 8 single code digit displays (-16.3%). At the other extreme digits are reported 31.4 percent more quickly in Density 4 dual-code digit-shape displays than in Density 4 single-code digit displays. An analysis of variance of these data failed to show any significant treatment effects.

## Discussion

Careful examination of the results obtained in Experiment 1 permit a number of conclusions. First, the relative gain or loss associated with color coding was never very large. Whenever a relative advantage for color coding exceeded, say, ten percent, it most often occurred when color coding was used in place of letters or in place of digits in displays which had used both letters and digits. In that case, other coding variables, e.g., familiar geometric shapes, when combined with letters or with digits, often led to equally large gains relative to the letter-digit dual-code condition. The relative gain or loss associated with color coding varied as a function of task and dependent measure; relative effectiveness of color coding was negligible for accuracy measures in all tasks and when response time was considered, the effect of color was much smaller for identification tasks than for search and locate tasks. The larger relative gain scores associated with color coding generally occurred in the dual-code displays and in the higher density displays.

Secondly, comparisons between results from the present experiment and the previously reported single-task experiments showed that the combined tasks (with inherent task uncertainty) and variations in exposure time had no differential effects on the relative gain or loss associated with color coding. Hence, while there was often an overall change in performance levels between the combined task and the single task experiments, there was no change in the relative effectiveness of color coding.

Third, the data suggest that the subject begins to process the entire stimulus array as soon as it is presented and before he knows which task he will be asked to perform. This conclusion is supported by the fact that properties of the stimulus array have significant effects on choice reaction performance even though the stimulus array is irrelevant for that task.

Fourth, highly practiced subjects demonstrate a strong tendency not only to process any and all potentially relevant information which is presented to them, but they also show a very strong tendency to organize and reorganize inputs from the display. This tendency to organize the inputs is most evident in the identification-memory task and it occurs as a function of heterogeneity of inputs (i.e., dual-code displays) and as a function of task demands. In the former case subjects exhibited a strong tendency to report all the stimuli from one target code before reporting those from the other. Which of the two target coding variables was reported first seems to vary with task demands. Hence, in the relatively simple single task conditions previously reported, subjects showed a tendency to report letters and digits before shapes or colors; in the present combined task experiment when the display density was low, subjects tended to report shapes and colors before letters and digits; and in the present experiment when density was high, subjects showed no preference or bias for reporting any given coding dimension before another.

Mean correct response time data from the identification-memory task also support the organizing tendency which varies with task demands. Hence, correct reaction times to letters and digits are only slightly affected by display density but correct response times to shapes and colors are much longer for density four displays (where subjects show a preference for reporting those codes first) than for density eight displays (where subjects exhibit no preference).

The importance of the subjects' tendency to encode all potentially relevant information and to organize and reorganize that information is evident in performance levels. Hence, performance is usually superior when there is a need and an opportunity for differential organization of input than when there is no need or opportunity for information segregation and reorganization. More specifically, performance is generally superior for dual-code display conditions than for single-code conditions. Furthermore, the incompatible dual-code display condition led to better performance than the compatible condition. In the former condition one set of values from each of the two coding variables was used exclusively for one task and the remaining values from each code were used for other tasks. Finally, it was generally true that color was most usefully employed as one of the coding variables if there was an opportunity or requirement for distinguishing one class of stimuli from another class of stimuli.

## EXPERIMENT 2: COMBINED TASK II

Experiment 2 was designed to extend the investigation of the relative effects of color coding to an even more complex total task than had been used previously. Moreover, the conditions of this experiment stressed the requirement for differential processing of the dual-code inputs. The number of tasks was increased to four by adding a same-different comparison to the three tasks used in Experiment 1. The comparison task required the subject to monitor three new single symbol displays, and to indicate as quickly as possible whether the symbols which were present were the same or different. In addition to the new task, the processing requirement of the total task was increased by a modification of the identification-memory task. In Experiment 1 the IDENTIFY request was always a signal for a full report of all of the stimuli in the matrix display. In Experiment 2, the message presented in the IDENTIFY display on dual-code trials could signal all the stimuli were to be reported, or that only those from one of the two target code dimensions were to be reported.

## Method

### Apparatus

The only change in the system was the addition of three single stimulus IEE display units. Those units provided the displays which were used to signal a comparison trial. They were located in a vertical column on the right-hand side of the display console and are illustrated in Figures 3 and 4. While the Numitron displays shown on the right side of the display console were exposed to the subjects, they were never used in Experiment 2.

The same films were used in the comparison task displays as were used in all of the other IEE units (except that the IDENTIFY request display had its own peculiar film). On any given comparison task trial, the subject had to determine whether all three displays contained the same stimuli (e.g., the letter C) or if one of the displays had a different stimulus than the other two (e.g., one had the letter C, or the digit 5, and the other two had the letter K). The subject was instructed to indicate the status of these three displays as rapidly as possible by pressing one button if they were not all the same (i.e., a "different" button) and another ("same") button if they were all the same. The "same" button was also the "terminate" button described earlier. The "different" button was newly-added button which was located immediately above the same-terminate button in the center of the control console.

### Subjects

Twelve male students enrolled at New Mexico State University were recruited to serve as subjects in Experiment 2. They were paid a fixed sum per session for their participation and were also given a monetary incentive based upon their performance. All subjects were between the ages of 18 and 24 and were right handed. In addition, they all had a visual acuity of at least 20/20 in each eye as measured with a Snellen chart and normal color vision in each eye as determined by the American Optical H-R-R Pseudoisochromatic Plates.

The subjects were assigned to one of two groups. The two groups of subjects were scheduled to run in four to five daily sessions on alternate weeks. This scheduling system was used to enable optimal use of the facilities and experimenters' time, and to allow at least a minimum degree of counter-balancing of conditions over successive sessions.

Procedure

Practice sessions. Each subject was given four weeks of extensive practice with each single task condition in isolation and with the several tasks combined in a series of discrete trials. The details of the procedures used for presenting these tasks have been fully described in a previous report (Christ and Corso, 1975), and in the method section of Experiment 1.

A series of familiarization trials were run during which each subject was given two daily sessions with each single task condition. Sessions 1 and 2 each had eighteen 48-trial blocks of choice reaction trials. These choice reaction trials used only the ACKNOWLEDGE display and the six response buttons; no matrix display was used. In those two sessions each of the four stimulus codes was used as a target over nine consecutive blocks of trials. Session 3 and 4 were used to familiarize the subjects with the single task search and locate condition. Over the two sessions each of the four single-code display conditions and four of the six dual-code display conditions were used once each. One single-code and one dual-code condition was used in each half-session; seven consecutive blocks of 48 trials were devoted to each display condition. Sessions 5 and 6 were devoted to the identification-memory task. There were six 20-trial blocks of single-code trials and six 20-trial blocks of dual-code trials per session.

Sessions 7 through 12 completely replicated the six experimental sessions of Experiment 1. As previously described, each session consisted of six single-code, six dual-code compatible, and six dual-code incompatible blocks of 30 trials each. Within each block of trials there were 10 choice reaction trials, 10 search and locate trials, and 10 identification-memory trials. Finally, Sessions 13 through 16 were practice sessions during which the subjects were each given experience with the experimental conditions used in Experiment 2.

Experimental sessions. Sessions 17 through 22 were the data collection sessions for Experiment 2. Each trial of these sessions began with the onset of the matrix display followed after 500 ms by the onset of one of the three small task request displays or by the three comparison task displays. Over a series of 48 trials each of the four tasks occurred equally often. On the 12 choice reaction trials the ACKNOWLEDGE display presented a target stimulus which the subject had to identify as rapidly as possible. On six comparison trials the three comparison displays all contained the same value of a target dimension and on the other six comparison trials one display presented one stimulus and the other two presented a different stimulus. On the choice reaction and comparison trials the matrix display contained 4, 8, and 12 sitmuli equally often. While the same single-code or dual-code stimuli were used in the matrix display as were used in the ACKNOWLEDGE display and in the three comparison displays, the contents of the matrix display were independent of the requested response. That is, the subject could ignore the matrix display since it was irrelevant.

Search and locate trials in Experiment 2 were exactly as they had been in Experiment 1. However, the procedures used for the identification-memory trials were modified for the present experiment. As in Experiment 1, the identification-memory trials were initiated by the onset of the IDENTIFY display. The message FULL in the IDENTIFY display served as a signal to report all of the stimuli that were in the matrix display. This full report request was presented on all single-code identification-memory trials but only on one-third of the dual-code trials. On the remaining dual-code trials, the subject was given a verbal message which requested a report of only half the targets in the display; only the targets in one of the coding dimensions were to be reported on these partial report trials. The verbal messages which signal the partial report trials were the words LETTER, DIGIT, SHAPE, or COLOR, depending upon the particular code combination being used during that session. If the dual-code sets in a given session consisted of letters and digits, the messages FULL, LETTER, and DIGIT were used on four trials to signal a full report request, a letter report request, and a digit report request, respectively.

The maximum duration of the joint presentation of the matrix and task request displays and the maximum interval for responding were exactly as they were in Experiment 1. There were always 48 trials in a block of trials and each of the four tasks occurred on 12 randomly selected trials. The only restriction on the sequence of conditions over trials was that no task and no matrix density condition could follow itself more than twice in a row. Single-code and dual-code display conditions were presented in six consecutive blocks of 48 trials each; the first block of trials was always a practice block, the other five blocks of trials were experimental blocks. Only the compatible dual-code display condition was used in Experiment 2; there were only 12 blocks of trials per session. The order of occurrence of single-code and dual-code display conditions was counterbalanced within and between subjects.

## Results

The data were analyzed separately for each task. Within tasks, the absolute levels of performance were analyzed separately for the single-code and dual-code display conditions. Only nine of the twelve subjects who began this experimental program actually completed all 22 sessions. Consequently, only the data from those nine subjects will be described below.

Choice Reaction Task

Accuracy. The number of correct choice reaction trials was determined over the 12 trials within a block of trials as a function of density, and over the five blocks of trials within a display condition. The subjects were very accurate. They were correct on 95.8 percent of the single-code trials and 96.7 percent of the dual-code trials. Incorrect responses occurred on fewer than one percent of the choice reaction trials and a failure to respond during the 1500 ms response interval on only about two percent of the trials.

Analyses of variance of the correct response data showed that there were no significant treatment effects for the single-code display condition. The only significant effects found for the dual-code display conditions were the main effect of code combination, $F(5, 40) = 2.57$, $p < .05$, and the three-way interaction of code combination, codes within combination, and density, $F(10, 80) = 3.05$, $p < .01$. While statistically significant, both effects were small. The accuracy scores ranged from a low of 94.2 percent for digit targets in a digit-color matrix to a high of 98.3 percent for letter targets in a letter-shape display.

Choice reaction time. An analysis of variance of correct choice reaction times showed no significant effects for the single-code condition and only density, $F(2, 16) = 4.05$, $p < .05$, significant for the dual-code condition. The overall choice reaction time with the single-code condition was 913 ms; for dual-code displays the reaction times were 866, 858, and 865 ms for densities of 4, 8, and 12, respectively.

## Search and Locate Task

Accuracy. The accuracy of location in the search and locate task was quite high. The number of correct and incorrect responses was pooled over the six trials within each level of density per block of trials, and then over the five blocks of trials within a display condition. Overall, subjects were correct on about 92 percent of the search and locate trials; they were incorrect on about 4 percent of the trials, and they failed to respond on about 4 percent of the trials. Density was significant at the .01 level for both the single-code, $F(1, 8) = 18.16$, and the dual-code conditions, $F(1, 8) = 12.39$. The only other factor which was significant was Code x Density; for the single-code condition, $F(3, 24) = 4.58$, $p < .05$ and for the dual-code condition $F(5, 40) = 4.32$, $p < .01$.

In both display conditions accuracy was higher for Density 4 displays than for Density 12 displays: 94.2 and 89.3 percent respectively for the single-code condition, and 95.0 and 91.0 percent for the dual-code condition. For both display conditions the interaction of code and density resulted from a lack of code differences when density was four, but significant differences when density was twelve. Pairwise comparisons showed that for Density 12, accuracy was lower for single-code color displays than for letters, digits, and shapes, and accuracy was higher for the shape-color and digit-shape dual-code displays than for the other four dual-code conditions.

Search and locate time. The response time for each correct search and locate trial of each subject was pooled over the six trials at each level of density within each block of trials, and then over the five blocks of trials within each display condition. Those data were used in analyses of variance which showed that density and code condition were significant effects for both display conditions. Density was significant at the .01 level for single-code displays,

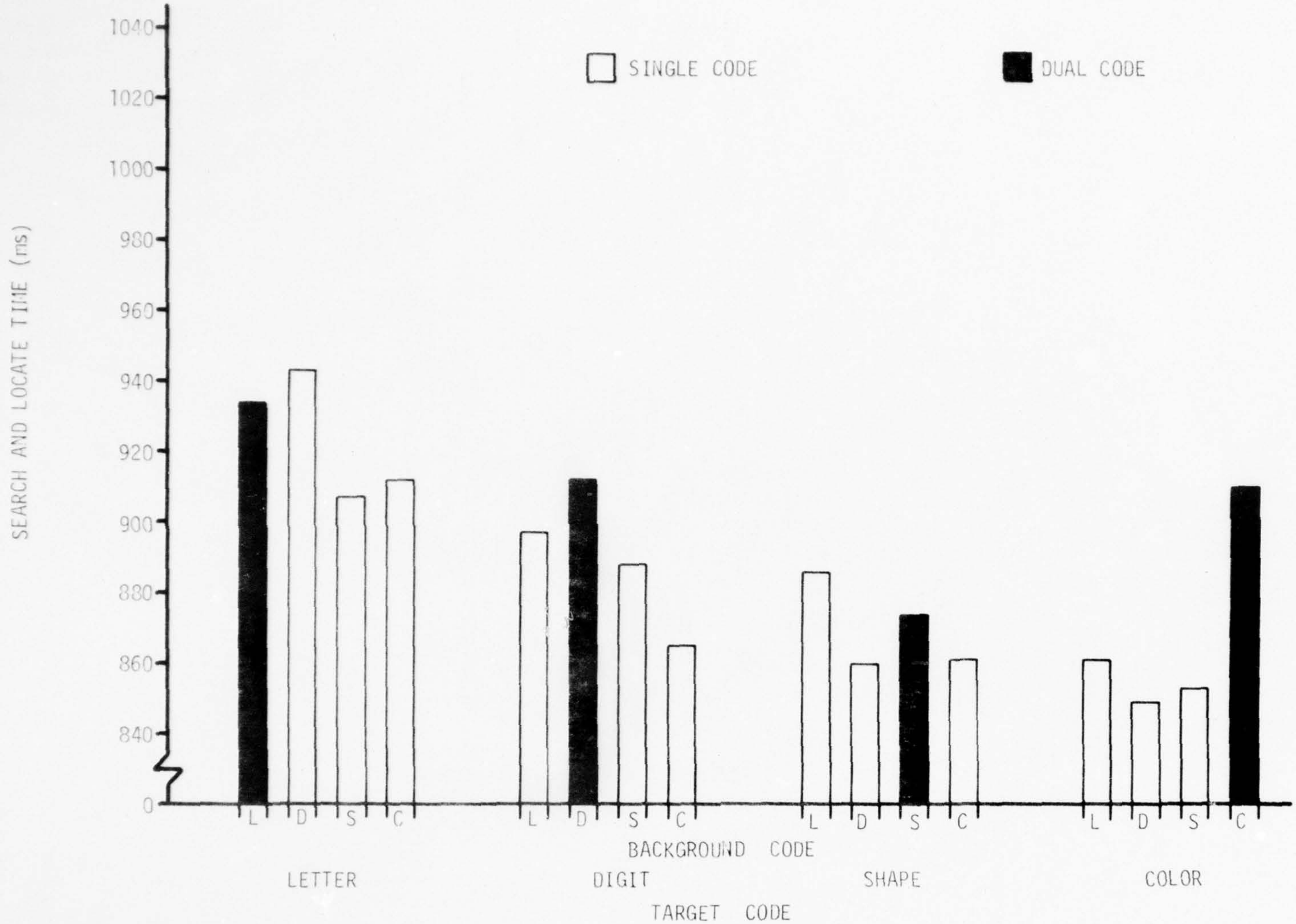


Figure 12. Search and locate time in Experiment 2 as a function of target and background code sets.

$\underline{F}(1, 8) = 348.41$, and dual-code displays, $\underline{F}(1, 8) = 467, 43$; code was significant at the .05 level for single-code, $\underline{F}(3, 24) = 4.47$, and dual-code displays, $\underline{F}(5, 40) = 2.69$. The only other effects which were significant were the interaction of code and density for the single-code condition, $\underline{F}(3, 24) = 3.72$, $\underline{p} < .05$, and the within code combination main effect for the dual-code condition, $\underline{F}(1, 8) = 17.91$, $\underline{p} < .01$.

Inspection of the data showed that location response time was shorter for Density 4 than Density 12 displays for both single-code (838 and 977 ms, respectively) and dual-code conditions (820 and 944 ms, respectively). The code main effect in the single-code condition was due to longer reaction times for letter targets than for the other three codes and shorter reaction times for shape targets than for the other three codes. The interaction of code and density for the single-code condition was nonsystematic. The main effect of code combination was due to longer reaction times for letters and digits than for shapes and colors (906 and 874 ms, respectively). The form of the relationships among reaction time, target codes and background codes is shown in Figure 12. As may be seen, reaction time is longer for the letter-digit combination than for any other dual-code condition. It may also be seen that reaction times are longer for the single-code than the dual-code displays.

Identification-Memory Task

Accuracy. The mean number of correct and incorrect (commission error) responses was determined separately for each subject by pooling over the trials within each density and within the full and partial report conditions. Those data were then pooled over the five blocks of trials within each display condition. Analyses were performed separately for the single-code, the dual-code full report and the dual-code partial report conditions. The number of correct reports per trial was significantly affected by density for each set of data:

$F(1, 8) = 7.42$, $p < .05$, 27.82, $p < .01$, and 12.07, $p < .01$ for the single-code and dual-code full and partial report conditions, respectively. The mean number of correct reports for the single-code and the dual-code full and partial report conditions were 3.8, 3.8, and 1.9 for the Density 4 displays and 5.6, 6.3, and 3.8 for the Density 8 displays. Those values correspond to 95 percent correct recall for all of the lower density matrices and 70, 79, and 95 percent accuracy for the higher density displays. The only significant effect for the number of correct report data was the main effect of code in the single-code condition, $F(3, 24) = 4.96$, $p < .01$. An examination of the data showed that accuracy was better for digit targets (83.8%) than for any of the other three single-code conditions (76.4%).

There were relatively few commission errors in the identification-memory task. The number of commission errors per trial for both single-code and dual-code whole report conditions was about .14 and .56 for Density 4 and 8 displays, respectively. The number of error responses in the dual-code partial report condition was equal to .12 per trial.

*Response time.* Mean response times over all correct responses were determined separately for each subject as a function of density, code, and display-report conditions. An examination of the overall effects showed that reaction times varied as a function of display-report conditions; grand mean correct reaction time was 810, 762, and 903 ms for single-code and dual-code full and partial report conditions, respectively.

The only significant effect found for correct response time in the single-code condition was the interaction of code and density, $F(3, 24) = 5.03$, $p < .05$. That effect was shown to be due to the longer response time with the color code-Density 4 condition (871 ms) relative to the other condition (808 ms). Code was the only significant effect for the dual-code full report condition, $F(5, 40) =$ 2.96, $p < .05$. Code, $F(5, 40) = 3.06$, $p < .05$ and density,

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$F(1, 8) = 223.05$, $p < .01$ were the only significant effects for the dual-code partial report condition. Mean response times in the partial report condition were 1023 ms for Density 4 displays and 784 for Density 8 displays. The same general trend with code combinations was found in both the full and partial report conditions. Pairwise comparisons showed that the only effects for target codes in the full report condition was between the two most extreme scores (letter-shape and digit-color). In the partial report condition the letter-digit combination had a longer response time than all other dual-code codes except the letter-shape combination.

Comparison Task

Accuracy. The number of comparison trials on which each subject was correct was summed over the 12 trials within each level of the density, code, and same-different conditions. A preliminary investigation of those data showed that the subjects were very accurate on the comparison trials; overall, in each block of 12 trials, the subjects were correct on 11.1 trials (93.0%), made error responses on .53 trials (4.4%), and failed to respond on the remaining .37 trials (2.6%).

Comparison reaction time. The time required to respond to the onset of the three comparison displays was pooled over trials as a function of density, code, and same-different status, separately for each display condition. An analysis of variance for the single-code display condition showed that code, $F(3, 24) = 6.31$, $p < .01$, and same-different status, $F(1, 8) = 5.72$, $p < .05$, were the only significant effects. Response time to "same" trials (897 ms) was faster than response time to "different" trials (928 ms) and the mean response time to letters, digits, and shapes (896 ms) was faster than the mean response time to single-code color displays (963 ms). An analysis of variance of the data from the dual-code condition showed that only Density x Same-Different Status,

$F(2, 16) = 4.66$, $p < .05$, was significant. An examination of that interaction effect did not suggest systematic trends in the data; the shortest response time was for Density 4-"same" trials (868 ms) and the longest response time was for Density 4-"different" trials (888 ms).

## Discussion

It was expected that the relative effectiveness of color coding might be greater in Experiment 2 than was the case in the previous combined task study because the greater task requirements might enhance the use of color coding. Actually, the overall levels of performance were the same in both experiments.

The results of Experiment 2 showed even less gain from using color coding than was found in the previous experiment. In the single-code conditions, color either had a negative effect or a negligible effect relative to achromatic codes. While in Experiment 1 color produced benefits both as a target code and a background code in the search and locate, and the identification-memory tasks, in Experiment 2 there was a loss in performance with color coding relative to achromatic coding in the locate task, and negligible or nonexistent effects for color in the other three tasks.

The failure to find evidence for relative differences with color might have been due to: (a) the fact that the subjects were more highly trained in Experiment 2 might have reduced the differences shown by the subjects of Experiment 1; (b) color might not actually make a large contribution in the types of discrete tasks situations used here or in the types of display configurations used in these experiments. Either one or both are possible.

## EXPERIMENT 3: INTEGRATED TASK

The objective of Experiment 3 was to explore the effects on performance of a complex information processing task with similarities to activities encountered in aircraft piloting and other related operations. The procedures involved in the experiment permitted an evaluation of both total task effects and effects on the single tasks previously used.

A multiple display-multiple task system was designed to represent a simplified but "realistic" air traffic control system. There was no intention of simulating the specific problems confronting air traffic controllers, nor the display-control hardware used in the air traffic control environment. As used in this experiment, the apparatus system provided several important advantages: (a) the same kinds of coding variables that were used in the previous combined task experiments were employed; (b) the same types of simple discrete tasks as were used previously were employed as subtasks; (c) the coding system included a type of multi-dimensional coding which could assume different values or meaning as a function of other display or task condition; (d) the overall system permitted the integration of the several tasks into a complex task so that the individual subtasks could be viewed as components of the same continuous goal-oriented task; (e) the overall system produced a problem for the subjects which was intrinsically motivating.

No formal predictions were made concerning the results of Experiment 3. It was expected, however, that the effects found for the various tasks in the previously reported combined tasks experiments would serve as meaningful baselines for interpreting the results obtained in the context of this integrated task. Also, if color is most likely to be most useful in more complex display complex-task situations it may prove to be relatively effective in this experiment.

## Method

### Apparatus

With some modification, the same multiple display-multiple task hardware system that had been used in the previously reported experiments was used in the present experiment. One set of modifications was concerned with the display console, another with the control console. Each of these sets of modifications will be described in this section.

Displays. All of the display units that were used in Experiments 1 and 2 were also used in the present experiment. In addition, however, three new display units were utilized, different stimuli were presented in the displays, and some new functions (and labels) were allocated to some of the old display units.

The new display units consisted of three banks of RCA Numitron digital readout displays. Each bank of displays consisted of a horizontal row of three digital readouts. These three-digit displays were located in a vertical column on the right-hand side of the display console; their locations are illustrated in Figures 3 and 4. As may be seen, each three-digit display unit was located just below one of the IEE single plane readouts that have been previously described as the comparison displays. This arrangement of single plane readouts and digital displays was used so that each pair of displays could convey a different type of information to the subjects. Note, the digital information was presented and, hence, will be discussed in British units of measurement.

The uppermost pair of displays was labeled ALTITUDE, the centrally located pair was labeled SPEED, and the lowermost pair was labeled HEADING. The three pairs of displays were designed to provide subjects with information concerning those three types of flight parameters. The single plane readout displayed a stimulus which identified a particular airplane, the associated digital displays presented the speed, altitude, and heading of that airplane, each in quantitative terms. Taken together, those three pairs of displays were the status displays, i.e., they provided the subject with an airplane's flight status.

The other displays shown in Figures 3 and 4 served the same functions as they had performed in the previous experiments. The three IEE units arranged in a vertical column, when presented without the associated digital displays, signaled a comparison task for which the subject had to indicate whether or not all three displays contained the same stimulus. The ACKNOWLEDGE, LOCATE, and IDENTIFY displays still signaled the occurrence of a choice reaction, a search and locate, and an identification-memory task, respectively. Those four classes of displays and the corresponding four discrete tasks that they signaled were exactly as were previously described. Taken together, those four display units were request displays, i.e., they requested some action of the subject.

The large center display presented a number of different symbols and, as before, the subject had to monitor the contents of the large display. The primary changes in the large display were that (a) it was continuously displaying anywhere from two to eight stimuli and (b) each of the stimuli in the display moved from one cell to any one of the adjacent cells, or it moved off of the display. For the present experiment, the large matrix display was designed to represent some air space over which the subject was to have some control. Consequently, the large matrix display was an area display.

The different symbols presented in the area display were designated as the "names" of aircraft "flying" within the given airspace. The subject was to control the flight of these aircraft by monitoring and, when appropriate, changing one of the forementioned flight parameters (altitude, speed, and heading). By careful manipulation of speed and heading the subject could also control the location of an aircraft within the four by four matrix of air space cells.

To facilitate the air traffic control scenario, new films were specifically designed to be used in the single plane readout displays. These new films consisted of six different alphanumeric messages, two relatively large open squares, and two relatively large open circles. The alphanumeric messages consisted of a letter-digit combination, the letter always preceding the digit in a left to right horizontal arrangement. The specific letter-digit messages were C2, C4, N4, N7, P2, P7.

The letter-digit combinations and the shapes were all centered in the projection area. The shapes were designed such that if a shape and an alphanumeric message were both projected at the same time, the shape would surround the alphanumeric message. Two instances of each shape were used so that they could be color coded; i.e., one circle and one square could be projected as a red shape and the other circle and square could be projected as a green shape. The projected height of the alphanumeric messages was 0.250 inches (0.46 cm). The projected circles had a diameter of 0.75 inches (1.90 cm) and the squares had height and width of 0.66 inches (1.68 cm). Color coding was accomplished through the use of Roscolene color filters. The filters used to produce the red and green codes correspond to the manufacturers film numbers 821 and 871, respectively.

With the exception of the IDENTIFY display, the same film was used in all of the IEE readouts. The 16 readouts in the area display used all six alphanumeric messages and the shapes which circumscribed the letter-digit messages: either both shapes in white (shape code), one shape in each of two different colors (color code), or both shapes in each of two different colors (shape-color code). The three comparison displays, the LOCATE display, and the ACKNOWLEDGE display each used only the six alphanumeric messages. The film used in the IDENTIFY display was designed to project one of three different messages for this experiment: the two-letter combination "CN", the single letter "P", and the single digit "4".

Controls. All of the response units that were employed in the previous experiments were also used in Experiment 3. The six IEE displays and associated buttons in the upper right-hand corner of the control console were used to identify the single target in the choice reaction task and the multiple targets in the identification-memory task. The standard arrangement of target-to-button mapping was from left to right, top to bottom row: C2, N4, P2, C4, N7, and P7. The four location indicator buttons in the lower left corner of the control console were used to specify the location (quadrant) of a target aircraft in the area display. The "different" button and the combined "same-terminate" button located in the lower center part of the console were used to respond to the comparison task and to terminate an identification-memory response interval.

The new controls consisted of a multiple function keyboard with an associated light-emitting diode digital display and three buttons arranged in a horizontal row immediately below the keyboard. These controls and the associated digital display were centered in the control console. They are illustrated in Figures 3 and 4. The small digital display is located directly above the keyboard. (British units of measurement were used for the keyboard entries.)

The multiple function keyboard consisted of 12 buttons arranged in a four row by three column matrix. The digits 1 through 9 were associated with and used as a label on the first nine buttons arranged left to right and top to bottom. The fourth row of buttons was used to initiate a clear the keyboard function, to designate the digit zero, and to initiate an enter function. Those three buttons were labeled CL, 0, and ENT, respectively. The numeric data entered on the keyboard were displayed in the small digital display above the keyboard. Pushing the CL button erased the numeric data previously entered on the keyboard. Pushing the ENT button caused the data previously entered on the keyboard to be fed to the PDP8/e minicomputer. Pressing either the CL or the ENT button caused the digital display to go blank.

The function of the keyboard, i.e., the meaning of the numeric data entered on the keyboard, was determined by the three horizontally arranged buttons located below the keyboard. Those buttons were labeled, from left to right, as follows: "A" to designate the altitude function; "S" to designate the speed function; and "H" to designate the heading function.

In addition to the hardware modifications just noted, several software modifications were introduced which affected the functions served by some of the controls previously employed. The six target identification buttons were used also to obtain detailed quantitative flight status information for a particular aircraft in the area display and to indicate which aircraft's altitude speed, or heading would be affected by the multiple function keyboard data. In addition to those new functions assigned to the target identification buttons, a second function was assigned to the "different" comparison button. That new function, called LAND, if initiated by pressing the button under the appropriate set of circumstances, would cause an aircraft shown in the area display to land.

Subjects

The same set of nine male subjects was used in Experiment 3 as had been in Experiment 2. As before, they were paid a fixed sum per experimental session for their participation and were also given monetary incentives designed to maximize their levels of performance. The subjects were assigned to one of two groups primarily on the basis of scheduling convenience. However, some effort was made to match the subjects in the two groups on the basis of data from the previous experiment. The two groups were scheduled to participate in four daily sessions on alternate weeks.

Integrated Tasks

The integrated tasks were presented within aircraft control scenarios. These scenarios or runs were designed to be five minutes in duration. During a five minute run, the subject could encounter only the aircraft control problem, or he could encounter the aircraft control problem and a series of requests to perform simple discrete tasks.

The aircraft control problem was run essentially as a continuous background When a run was initiated it began with an aircraft control problem and that problem was before the subject except when a response was requested for one of the discrete tasks. Each of the four discrete tasks occurred three times in each run. The order in which the discrete tasks occurred was random with the restriction that no discrete task could occur more than twice in succession. The time interval between the discrete tasks ranged from 10 to 40 seconds, with a mean intertask interval of 20 seconds. The sequence of tasks, the specific request made when a task was initiated, and the time intervals between tasks were all predetermined in the construction of a scenario. When a discrete task was initiated the aircraft control problem was effectively frozen until the task had been terminated.

Since each of the discrete tasks have been fully described in connection with Experiments 1 and 2, only a brief description will be given of their characteristics in the present experiment. The choice reaction task was initiated whenever a letter-digit aircraft label was presented in the ACKNOWLEDGE request display. The subject had to acknowledge the presence of this target aircraft by identifying it within three seconds of the onset of the ACKNOWLEDGE requests. When the comparison task was initiated any lighted Numitrons were turned off and three predetermined alphanumeric messages were presented in the three IEE status displays. The three messages were all identical, or one of them was different from the other two. The subject had to determine that a comparison trial was in progress and indicate whether or not the three messages were identical by pressing either the "same" or "different" button. The search and locate task was initiated whenever one of the alphanumeric messages corresponding to an aircraft on the area display was presented in the LOCATE request display. The subject had to search for and indicate the location of the designated aircraft by pressing the appropriate location (quadrant) button. Each of the three tasks caused the aircraft control problem (i.e., the contents of the area display) to "freeze" for three seconds or until the subject responded, whichever occurred first.

The identification-memory task was signalled by the presentation of a message in the IDENTIFY request display and by the simultaneous offset of the area display. Hence, the subject was required to identify all or a selected portion of the items on the area display from memory. The message presented in the IDENTIFY request display was one of three, as follows: (a) "CN" was a request for the subject to identify only those aircraft whose label included the letter C or N; (b) "P" was a request for the subject to identify only those aircraft whose label included the letter P; (c) "4" was a request for the subject to identify all the aircraft which were on the area display at the time the request was initiated. The duration of an identify task, and hence the interval during which the area display was blank and during which the subject could respond, was a function of the number of aircraft on the area display. A maximum of 1000 ms per aircraft was allowed for an identification-memory trial. The trial terminated when the maximum allowable time had elapsed or when the subject pushed the terminate button, whichever occurred first.

Aircraft control. When an aircraft control run was initiated, two to four of the C or N aircraft (which were under the subject's control) and zero to four P aircraft (which were under computer control) appeared on the area display. The number of aircraft in the area display, their initial location, heading, speed, and altitude (expressed in British units of measurement) were all predetermined and were specified in the construction of a scenario.

The P aircraft were the "computer's aircraft", and could not be examined, controlled or interfered with in any way by the subject. The primary function of those aircraft was to increase the density of the area display and to add some dynamic noise to that display. The P aircraft also served as targets in the discrete tasks. The computer program would maintain up to four P aircraft, their velocities were constant throughout a run but once they ran off the area display, their headings and locations were randomized for their reappearance. Once set in motion they go their own way until they run off the area display.

The C and N aircraft could be presented as only alphanumeric messages, or with altitude and/or velocity status coding (i.e., area status coding). Altitude or altitude and velocity was coded onto the area display by the shape which surrounded the alphanumeric message and/or by the color of the shape which surrounded the alphanumeric message. If the altitude of an aircraft was greater than or equal to 10,000 feet, the alphanumeric message was surrounded by a white circle or by a red shape. If the altitude of an aircraft were less than 10,000 feet, the alphanumeric message was surrounded by a white square or by a green shape. If both altitude and shape were coded onto the area display, either shape or color coding was used to designate high and low altitude. Whichever code was not used to designate altitude was used to designate speed. A square or green shape designated an aircraft traveling at 400 or more miles per hour (mph) and a circle or a red shape designated a speed of 350 mph or less. It was, therefore, possible to present the C and N aircraft in any one of five formats: (1) a unidimensional format in which only the aircraft's identifying alphanumeric name was presented on the area display; (2) and (3) two dimensional formats in which the aircraft's identifying name and its altitude (the latter coded by color and shape, respectively) were presented on the area display; (4) and (5) three dimensional formats in which the aircraft's identifying name and its altitude and speed (coded by color and shape or shape and color, respectively) were presented in the area display.

Flight parameters. The "rules" for the three flight parameters are as follows:

(1) Altitude data were handled in 100-foot increments; e.g., if the altitude status display read 100, the altitude of the aircraft was 100 x 100 or 10,000 feet. Minimum allowable altitude was displayed as 005 (500 feet); maximum allowable altitude was 350 (35,000 feet). An aircraft shown on the area display which was directed to an altitude over or under these limits crashed.

(2) Speed data were handled in 50 mile per hour increments. Data entered by the subject were rounded to the nearest lowest 50 mph mulitple; e.g., an entry of 270 mph was translated to 250 within the computer program (although the status display showed the 270 which had been entered). The minimum allowable velocity was 100 mph; maximum was 650 mph. If an aircraft on the area display was directed to a speed which exceeded those limits, it would crash. The velocity rounded to the nearest lowest 50 mph multiple was used to determine how long an aircraft remained in one location (one cell) on the area display. The exposure time per cell was computed on the assumption that an aircraft had to travel a distance of one mile to traverse a cell. The time intervals encountered ranged from 5.5 seconds (650 mph) to 36 seconds (100 mph).

(3) Heading was handled in 45 degree increments. Data entered by the subject were rounded off to the nearest 45 degrees, although the status display

showed the actual data entered by the subject. If a heading greater than 360 degrees was entered it was ignored.

Status request. The subject could request the exact quantitative status of any of his controllable aircraft by pressing the appropriate identification button. Hence, if the button for, say, aircraft C2 were pushed, the three IEE status displays would all present the message "C2" and the Numitron displays would present the current decimal values of altitude, speed, and heading. A request for status identified which aircraft the subject was interested in, and any change in flight parameters was considered to be for the aircraft selected by the last status request.

Changing flight parameters. Flight parameters were changed by pressing one of the "come-to" buttons located under the keyboard to indicate which parameter -- altitude, speed, or heading -- to change, then entering the new value into the keyboard. When the keyboard enter button was pressed, the computer program made the required changes in the selected aircraft's status. If those changes affected the area status code, the area status code was changed appropriately (e.g., if a new altitude caused the color code to change from red to green, the change was made).

Landing an aircraft. Landing a C or N aircraft was accomplished by maneuvering the aircraft into the proper combination of flight parameters and then pressing the LAND button. The proper set of conditions which had to be satisfied in order to land successfully were the following: the aircraft had to be at an altitude of 005 (500 feet); it had to be at a velocity of 100 (100 mph); it had to be in one of the four center cells of the area display; and it had to be on a heading which directed it toward the center of the area display (the landing strip was assumed to be an X-shape located exactly in the center of the area display). If these criteria were met, successful landing was indicated as follows: a) the aircraft disappeared from the area display and b) the status display Numitrons showed all zeros for that aircraft.

Aircraft crashes. A crash was indicated when (a) the aircraft disappeared from the area display and (b) the status Numitrons were nulled (off) for that aircraft. Crashes occured under the following circumstances:

(1) An unsatisfied landing criterion

(2) An altitude entered at less than 500 feet or more than 35,000 feet

(3) A velocity entered of less than 100 mph or more than 650 mph

(4) The aircraft was allowed to fly off the area display

(5) A midair collision occurred

A midair collision could occur only among two or more C or N aircraft; a collision could not occur between a P and a C or N aircraft nor could two or more P aircraft collide. If all C and N aircraft are landed and/or allowed to crash the program terminated.

Integrated task scenario generation. Forty aircraft control-discrete task runs were generated by constructing a set of four runs for each of the ten combinations of aircraft formed by crossing zero to four P aircraft with two or four C and N aircraft. The resulting runs had densities which varied from 2 to 6 for two controllable aircraft and from 4 to 8 for four controllable aircraft. Aircraft were randomly assigned to runs with the restriction that each of the four controllable aircraft would occur equally often within each set of four runs. The initial location of all aircraft were limited to the outside 12 cells of the area display; no more than one aircraft could occupy the same cell at the beginning of a run. The only restriction placed upon initial headings was that the initial move made by an aircraft would not take it off the area display. When altitudes and speed were dichotomized around 10,000 feet and 350-400 mph, respectively, four combinations of high and low, fast and slow aircraft could be created. Each of these four combinations had to occur at least once in each set of four runs and each had to occur once in each individual run when there were four controllable aircraft.

Each of the four discrete tasks occurred three times in each sequence. The three comparison task trials were constructed so there would be two "same" comparison trials and one "different" trial. Each of three types of identification task occurred once in each run; a whole report, a CN aircraft partial report, and a P aircraft partial report each occurred in each run.

The target whose position was requested in the search and locate task had to appear once and only once in the area display. Consequently, if a controllable aircraft was initially designated to be a target and if that aircraft had crashed or landed, the computer program would randomly select a controllable aircraft that was on the area display to be used as a target. Also, computer controlled P aircraft which were designated as occurring more than one time could not be designated as a target in the search and locate task. The choice reaction task could have any of the six possible aircraft names used as a target; the choice reaction target could be on or off the area display.

While targets were randomly assigned to each task, an attempt was made to assure that each aircraft occurred only once per task per run and that over successive runs the various parameters of the target (e.g., the position of the different target in a comparison display) were balanced over all possible values.

Procedure

Practice with the new target messages. Two sessions were devoted to familiarizing the subjects with the new films; and, more particularly, with the six letter-digit combinations which were used as targets in Experiment 3. During the first session each subject was given 12 blocks of 30 trials each from those described and used in Experiment 1. The second session consisted of 12 blocks of 48 trials each as described and used in Experiment 2. Consequently, each subject obtained some practice using the new target stimuli and their associated responses. More specifically, each subject received 528 trials of practice using the new targets in each of the choice reaction, search and locate, and identification-memory tasks and 144 trials of practice in the comparison task. The details of the procedures used during Sessions 1 and 2 is given in the method sections of Experiments 1 and 2, respectively.

Practice with the aircraft control problem. To introduce the new integrated task to the subjects, each subject was required to participate in one session of 17 runs and three additional sessions of 12 runs each. During each of these four sessions, the subjects were instructed to land as many of the aircraft as they could in a four-minute time interval. The discrete tasks and the area display status coding were not used in any of those practice sessions. The general procedure during each of these sessions was to begin the session with the easiest runs (those with only two controllable aircraft and relatively few noncontrollable aircraft), and gradually progress to more difficult runs during the session. Subjects were given considerable feedback during the first two sessions. By the third and fourth sessions feedback concerning overall performance levels was provided only during the 5-minute rest period given halfway through each session. At the end of the fourth session all subjects were landing at least two of the four controllable aircraft present in the test runs. Each subject participated in a fifth practice session that did not contain any discrete tasks. During the first 6 runs of Practice Session 5, the subjects were instructed to land as many aircraft as rapidly as possible. Then, after a five-minute rest period the subjects were given 6 additional runs of 5-minute durations, with the instruction to keep all of the aircraft flying for the total duration of the sequence. The subjects were put on an incentive system beginning with the second half of Session 5. To encourage maximum levels of performance, the subjects were promised a 5-cent bonus for each aircraft still flying at the end of each run, no bonus for aircraft that had been landed, and they lost 5 cents for any aircraft that crashed or was otherwise lost.

Experimental sessions. During each experimental session the only independent variables (other than successive runs) were the numbers of controllable and uncontrollable aircraft and, consequently, the total density of aircraft on the area display. Over three successive blocks of sessions, the number of coding dimensions used in the area display was varied. More specifically, one, two, or three dimensions were used over three successive blocks of sessions representing alphanumeric labels only, the aircraft labels plus area display altitude status coding, and the aircraft labels plus area display altitude and speed status coding, respectively. The type of code used for each status code, color for altitude and shape for speed or vice versa, was used as a between-subjects variable.

During the first block of sessions, called Phase 0, both groups of subjects participated in three sessions of seven five-minute runs each, for a total of 21 runs. No area status information was presented on the area display during any of those runs, the status information concerning altitude and speed was only available on the Numitron displays. The aircraft control problem in each of these, and all subsequent runs, was interrupted twelve times by requests to perform the discrete tasks, as previously described. The initial run in each session was designated a practice run. The practice runs always had two controllable aircraft and no noncontrollable aircraft. During the first sequence all runs began with four controllable aircraft; the first three experimental runs had no P aircraft, the fourth run had two P aircraft, and the fifth and sixth runs had four P aircraft. During the second and third session of

Phase 0, the first three experimental runs had two controllable aircraft, the last three runs had four controllable aircraft. The number of noncontrollable aircraft successively, was 2, 3, and 4 within each half of the session.

The second block of sessions, called Phase 1, was devoted to runs which presented altitude status on the area display. For one group of subjects altitude information was coded on the area display by a circle or a square which surrounded the controllable aircraft's identifying alphanumeric label; the circle indicated that aircraft was above 10,000 feet, the square that it was below 10,000 feet. For the other group of subjects altitude information was coded by color. One-half the subjects in this group had the altitude information presented in a colored circle; the other half had altitude coded by a colored square. For both groups, the color of the surrounding shape was red if that aricraft was below 10,000 feet and green if that aircraft was at or above 10,000 feet. In addition to this area status display for altitude, more specific information concerning altitude, speed, and heading were still available, if requested, from the Numitron displays. Note that no altitude information of any kind was available for the noncontrollable P aircraft.

Both groups of subjects participated in three training sessions of seven five-minute runs. The number of controllable aircraft was two for the first three experimental runs in each training session and four for the last three experimental runs in each training session; the number of noncontrollable aircraft increased from 2 to 3 to 4 within each half of each session. After completion of those three training sessions, each subject participated in a fourth session which had two experimental runs of the type just described where altitude status was presented on the area display and then four additional experimental runs which had no area status information. Hence, during that fourth session data were obtained on the subject's level of performance in the Phase 1 type runs and in the Phase 0 type runs; the Phase 1 runs were criterion runs and the Phase 0 runs were control runs. The number of controllable aircraft was four for all the runs in Session 4. The number of noncontrollable aircraft was three during the two Phase 1 criterion runs and during the first two Phase 0 control runs; there were four noncontrollable aircraft during the last two Phase 0 control runs. Hence, if noncontrollable aircraft affect the difficulty of the integrated task runs, the Phase 0 control runs were more difficult than the Phase 1 criterion runs.

The third block of sessions in Experiment 3 were called Phase 2 sessions. These sessions were devoted to runs which presented both altitude and speed status on the area display. The group of subjects who previously had altitude coded by shape still had altitude coded by shape but now also had speed coded by color. For that group the shape which designated the altitude of the aircraft was colored red if the aircraft was traveling at a speed equal to or less than 350 mph and green if the speed was greater than 400 mph. The other group of subjects who previously had altitude coded by the color of a shape still had altitude coded by color but now also had speed coded by shape. For this second group the circumscribing shape was a circle if the aircraft was traveling at a speed equal to or less than 350 mph and a square if the speed was greater than 400 mph.

Both groups of subjects participated in three sessions of seven five-minute runs during Phase 2 which were essentially the same as the initial three sessions of Phase 1. The only differences in the initial three sessions between Phase 1 and Phase 2 were the number of status codes presented in the area display and the precise parameters assigned to aircraft at the initiation of each run. The fourth session of the Phase 2 block of sequences consisted of four experimental runs with both altitude and speed status coded on the area display (just as was true for the preceding three sessions) and then four additional runs during which there was no area status information. Hence, during Session 4 of Phase 2 data were obtained on performance levels in Phase 2 criterion runs and on performance levels in the Phase 0 control runs.

The number of controllable aircraft was two during the first two Phase 2 criterion runs and four during the last two Phase 2 criterion runs and during all four Phase 0 control runs. The number of noncontrollable aircraft was 2, 4, 3, and 4, for the Phase 2 criterion runs; three noncontrollable aircraft were used in the first two Phase 0 control runs and four in the last two Phase 0 control runs. Hence, if the numbers of controllable and noncontrollable aircraft affect overall integrated task complexity, the Phase 0 control runs were more complex than the Phase 2 criterion runs.

To supplement the objective data that were obtained over the preceding experimental sessions, each subject was interrogated when he completed the last session. The interrogation was concerned with determining the subject's thoughts about and possible preferences for the coding variables they had experienced.

## Results

Only six of the nine subjects who began Experiment 3 participated in all of the practice and experimental sessions. Three of those six were from Group A which had altitude status color coded and speed status shape coded in the area display; the other three subjects were from Group B which had those coding conditions reversed. The results which are reported in this section will be based exclusively upon the performance measures obtained from those six subjects.

The only measure of performance analyzed from the aircraft control problem was the count of the number of aircraft flying at the end of each run. Those data were summed over the six runs in each of Sessions 1-3 for each phase of the experiment and converted into percentage scores; i.e., the percentage of all controllable aircraft which were present at the initiation of each run which were still present (flying) at the end of the run. Similar data manipulation was done for the aircraft control measures obtained in the criterion and control trials in the fourth session of Phases 1 and 2.

There were three measures of performance derived from each of the following discrete tasks: choice reaction, search and locate, comparison. Those measures were based upon the number of times each task request was responded to per run, the number of correct responses per run, and the reaction time of each correct response per run. Those measures were pooled over the respective task requests per run and then over the six runs per session. The resultant data were the percent trials responded to, the percentage of responses which were correct, and the mean correct response time for each of the three discrete tasks per each session in Phases 0, 1, and 2.

The identification-memory task results were handled separately for each of the three types of requests. On each run, the time to begin a multiple target report sequence, the number of correct responses, and the mean response time pooled over all correct responses was determined for the full report, the partial report of controllable aircraft, and the partial report of noncontrollable aircraft. Those measures were subsequently pooled over the six runs per session for each of Sessions 1-3 in each phase. The results were the mean number of correct reports per run, the mean time to make the first response per run, and the overall mean correct response time per run. In addition, those same measurements were pooled over the criterion and the control runs in the fourth session of Phases 1 and 2.

Pre-criterion Training Performance

The data for each task were examined as a function of the first three training sessions per phase, separately for each phase and group. The resulting 3x3x2 factorial design was used in analyses of variance, separately for each task and measure.

No significant treatment effects were found for the aircraft control problem. Pooled overall conditions, 84.1 percent of the aircraft initially presented were still flying at the end of a run. Significant main effects for training sessions were found at the .05 level or better for only the following tasks and measures: for the choice reaction task, percent responded, $F(2, 8) = 13.77$, and percent correct, $F(2, 8) = 23.70$; for the locate task, percent responded, $F(2, 8) = 16.96$; for the comparison task, percent responded, $F(2, 8) = 6.36$, and percent correct, $F(2, 8) = 6.36$. Those results suggest that the subjects became increasingly proficient in noting the presence of a request and in correctly responding to that request within and across all phases of the experiment when those requests signaled a choice reaction, search and locate, and comparison task. There was no overall effect of training session on the identification-memory task.

There were indications that the effects of training were not equal for the different phases of the experiment and for the two groups of subjects. Interaction effects between session and phase were only found for accuracy measures and then only for the search and locate task $F(4, 16) = 5.42$, the comparison task, $F(4, 16) = 6.57$, the partial report of controllable aircraft, $F(4, 16) = 5.21$, and the partial report of uncontrollable aircraft, $F(4, 16) = 3.01$. Three way interactions among session, phase, and group were found for only the accuracy data for the locate task, $F(4, 16) = 3.20$, and for the comparison task, $F(4, 16) = 3.67$. Generally, these effects showed that while accuracy on the first session of each phase increased from Phase 0 through Phase 2, and while there may have been differences between the two groups early in training for each phase, the effects were eliminated or at least greatly attenuated by the last session of each phase. The main effect of phase and one interaction between phase and group that were found to be significant were not pursued since the general levels of improved accuracy that those effects showed were not possible to fully interpret since phase was completely confounded with overall levels of training in Experiment 3.

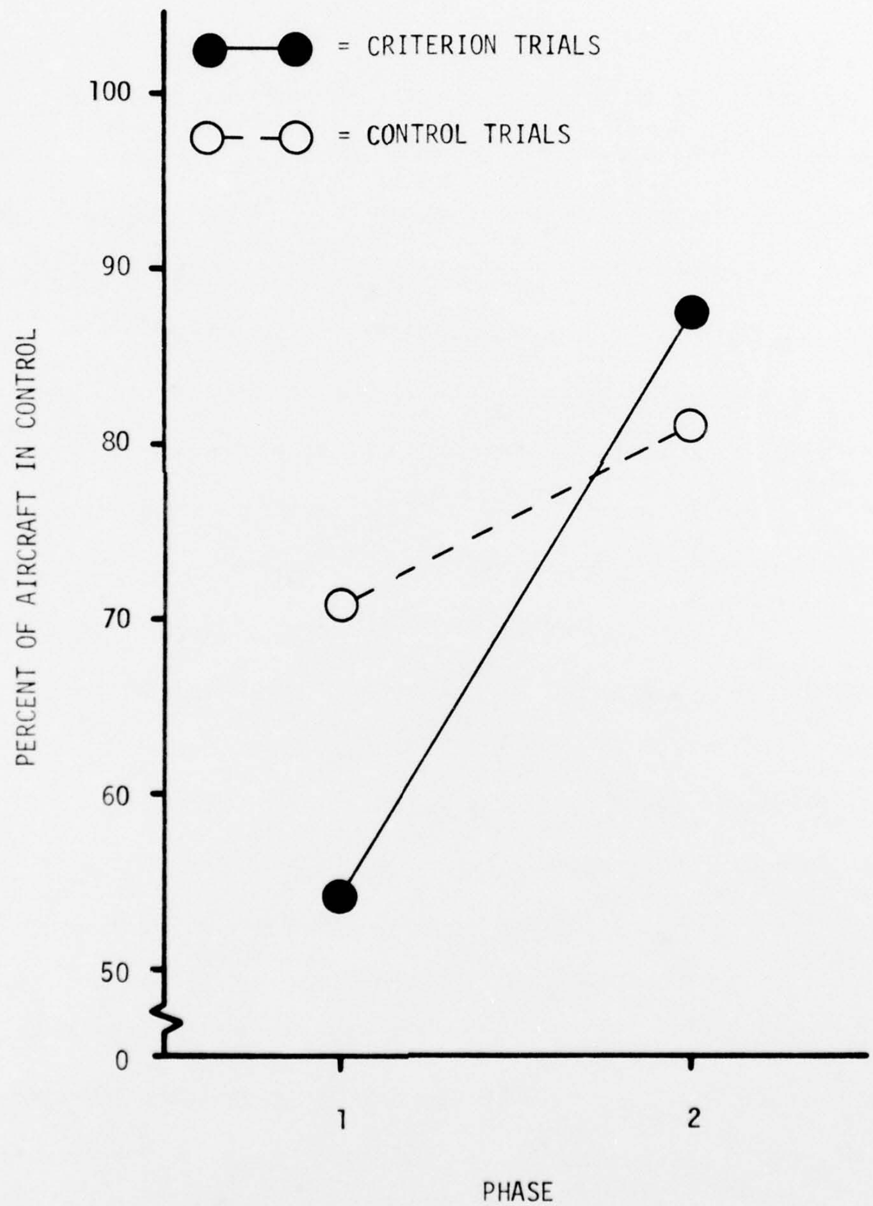
The major conclusion that could be drawn from the analyses of pre-criterion levels of performance is that with the exception of an overall effect of training on accuracy, the data were all surprisingly homogeneous. No effects were found for the reaction time measures. More specifically, the amount of information present in the area display did not aid the subjects in the aircraft control problem nor did it unburden the subjects so that they could improve their performance in the discrete tasks. Furthermore, while there was a general tendency for subjects in Group A to out perform subjects in Group B that effect was never significant and the trend also existed during Phase 0 in which the experimental treatment was the same for both groups.

Criterion Performance

The results which were obtained in the fourth session of Phase 1 and 2 were assumed to be the most valid measures of the effects of coding in the integrated task displays. In those sessions we have measures of performance for each task which show the effects of one and two levels of shape and color coding which are not confounded with training effects.

Figure 13 illustrates the nature of the effects that are obtained from these criterion sessions. That figure shows the percentage of aircraft that are flying at the end of a run as a function of the phase of the experiment, separately for criterion trials and control trials. Those results are pooled over the group effect which was not significant for these data. Recall that only

Figure 13. Percentage of initially present aircraft on the area display at the end of a run in Experiment 3 as a function of phase and criterion vs. control trials.



altitude was coded during the criterion trials of Phase 1 and both altitude and speed were coded during the criterion trials of Phase 2. There was no status coding in the area displays for the control trials of either phase; practice is the only treatment effect for the control trials.

An analysis of the data that are summarized in Figure 13 showed that there was an overall treatment effect on the aircraft control problem, $F(3, 12) = 15.50$, $p < .01$. Paired comparison tests showed that in Phase 1 the subjects performed better in the aircraft control problem during the control trials than in the trials which used color or shape to code the altitude of controllable aircraft. Furthermore, while aircraft control performance increases significantly during both criterion and control trials between Phase 1 and Phase 2, there was no difference in performance between the control trials and the criterion trials in Phase 2. In conclusion, then, the data in Figure 13 show that aircraft control performance is either no better or worse if shapes and/or colors are introduced as redundant cues for determining the flight status of aircraft. The change in performance which accompanies the addition of a second redundant coding variable in Phase 2 appeared to be as much due to practice effects as to any effect of coding per se.

No effects of phase or criterion vs. control conditions were found for the accuracy data derived from the choice reaction, search and locate, or the comparison tasks. However, correct response time was shown to be affected by the criterion vs. control conditions in Phase 1 of the search and locate and the comparison tasks, $F(3, 12) = 8.27$ and $7.87$, $p < .01$ in each case. These results are shown in Figure 14 along with comparable results for the choice reaction task. Figure 14 shows mean correct response time as a function of phase and criterion vs. control trials separately for each of those three tasks. The figure indicates that reaction times in the search and locate task and in the

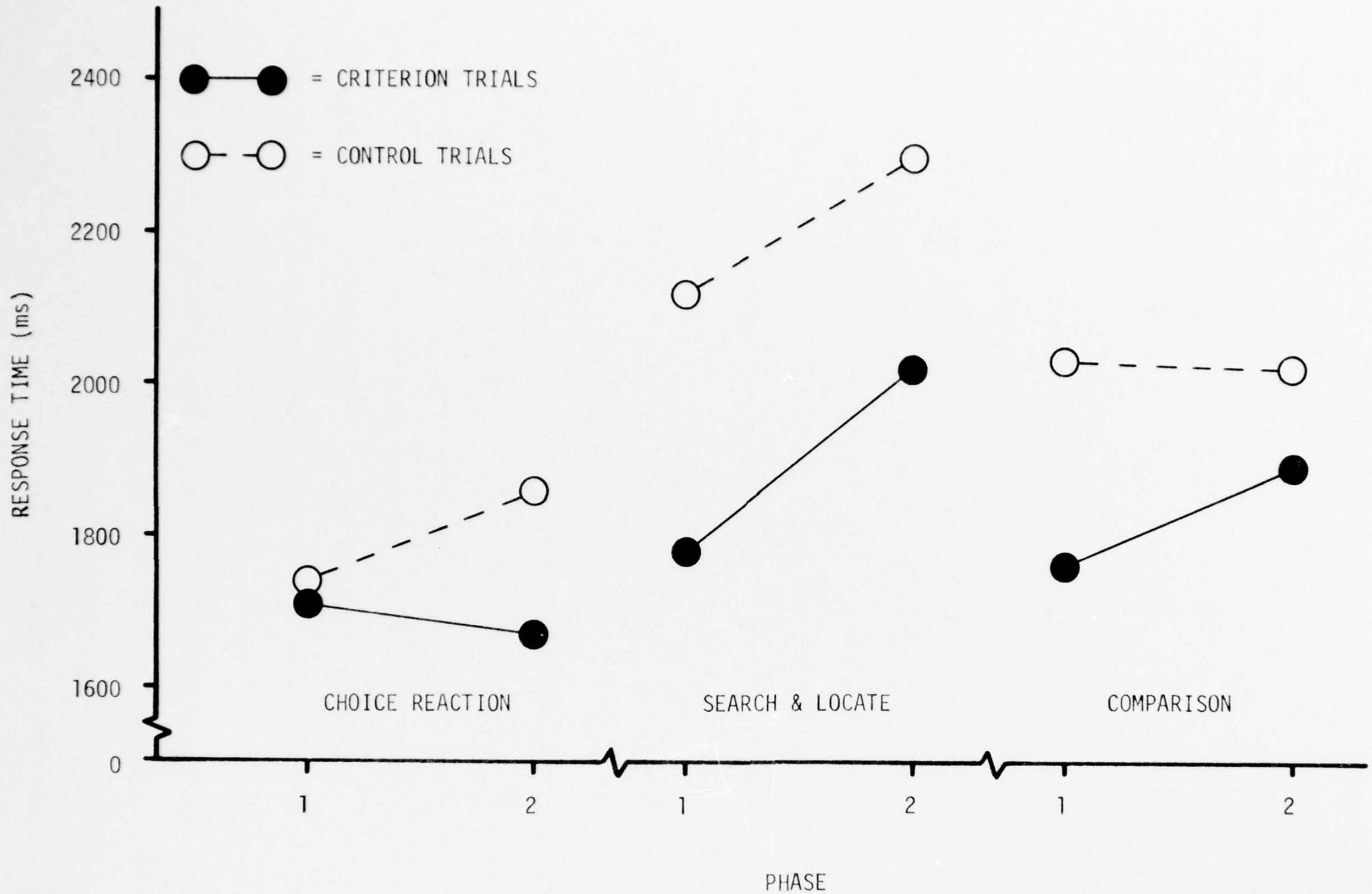



Figure 14. Mean response time in the choice reaction, search and locate, and comparison tasks of Experiment 3 as a function of phase and criterion vs. control trials.

comparison task were shorter when color or shape was used to code altitude in the area display than when there was no status code used in the area display. It was also shown that response time on the criterion trials increased when a second code was added to the area display in Phase 2; no changes in performance occurred between Phase 1 and 2 for the control trials and there were no differences between control and criterion trials in Phase 2.

Area display coding was also shown to affect performance levels in the identification-memory tasks. These effects are summarized in Figure 15 which shows the mean time to make the first response, the mean number of correct responses, and the overall mean correct response time per run as a function of full vs. partial report conditions, phase, and criterion vs. control trials. The data shown in the figure for partial report were pooled over the two partial report conditions since the same trends were found in the data for both conditions.

In the partial report conditions first response time was affected by area display status, $F(3, 12) = 7.79$, $p < .01$ and 3.82, $p < .05$ for the controllable and noncontrollable aircraft conditions, respectively. There were no significant effects on first response time in the full report condition. First response time in the partial report conditions were significantly affected by altitude status coding in Phase 1. However, while first response time decreased from Phase 1 to Phase 2 for the control trials, there was no change between phases for the criterion trials. The net effect was that there was no effect of area display coding in Phase 2. It thus appears that using shape coding or color coding to designate the approximate altitude of controllable aircraft enabled the subject to more quickly begin a partial report of the controllable or the uncontrollable aircraft. Hence, it was not the altitude status information *per se*, but rather the increased differentiation between controllable and

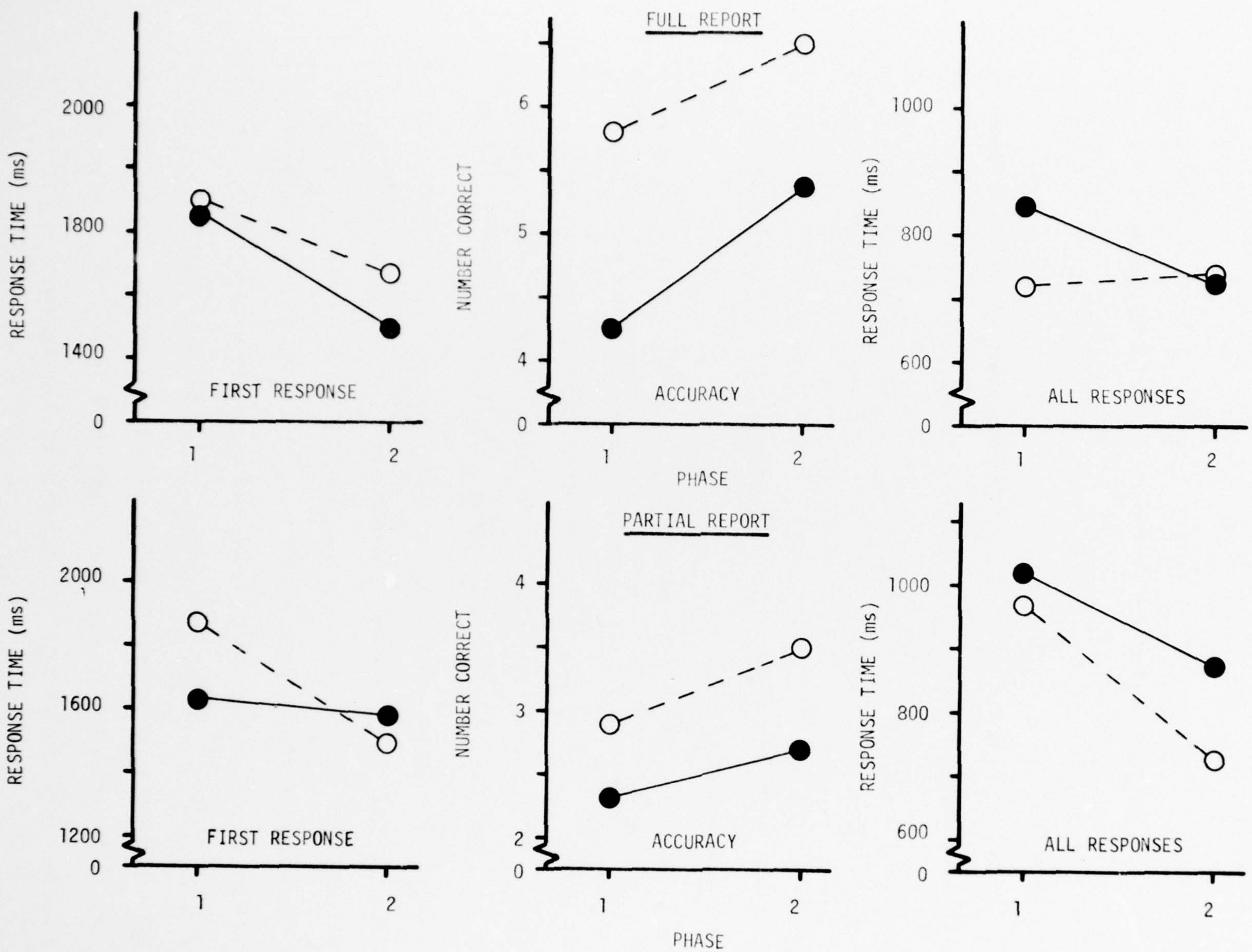



Figure 15. Mean first response time, mean number correct, and mean overall correct response time in the full and partial identification-memory task of Experiment 3 as a function of phase and criterion trials (solid lines) vs. control trials (dashed lines).

uncontrollable aircraft which improved the time required to begin a multiple target report. Since performance on control trials increased from Phase 1 to Phase 2 but performance on criterion trials does not change, it also appears that the use of shaped <u>and</u> color (or the encoding of altitude and speed status) in Phase 2 criterion trials produced an interference effect which offset the benefits of practice.

Status coding in the area display adversely affected accuracy of identification-memory performance in both the full report condition, $\underline{F}(3, 12) = 17.29$, and in the partial report condition of controllable aircraft, $\underline{F}(3, 12) = 10.30$, and of noncontrollable aircraft, $\underline{F}(3, 12) = 30.74$, all at the .01 level. Hence, while performance accuracy increased from Phase 1 to Phase 2 on both criterion and control trials, accuracy was always higher on the control trials than on the criterion trials.

Overall mean correct response time in the identification-memory task was affected by the independent variables only for the partial report conditions, $\underline{F}(3, 12) = 5.70$, $\underline{p} < .05$ for the controllable aircraft condition and $\underline{F}(3, 12) = 7.13$, $\underline{p} < .01$ for the noncontrollable aircraft condition. Generally, it may be seen that mean response time was longer on criterion trials than on control trials. However, paired comparison tests showed that the only significant effect in the partial report conditions was a decrease in correct response time from Phase 1 to Phase 2.

The major conclusion that may be drawn from the criterion session levels of performance is that the use of color and shape codes to provide partially redundant information concerning the flight status of controllable aircraft may affect performance in discrete subtasks which are integrated with the overall air traffic control problem. Whether or not there is an effect on discrete task performance, and the direction and magnitude of those effects, is a function of the specific task in question and the specific dependent measure employed. In no case will the effects be expected to vary due to color vs. shape coding.

Subject Preferences

When the subjects were asked if they liked the color and the shape coding they all replied in the affirmative. However, when they were asked if the color and the shape coding helped in the air traffic control problem, there were some differences of opinion. The subjects indicated a preference for the code which encoded the speed status information, and they expressed a belief that the speed status information improved their performance in the air traffic control problem. This finding was unanimous over all six subjects and was found whether speed was encoded by color or shape. Some subjects reported, and it was apparent to the experimenters, that the strategy adopted by the subjects was one in which they began each run by slowing down all aircraft. This strategy provided more time to avoid crashes between aircraft or to prevent aircraft from flying off the area display.

When subjects were asked if the area display status information helped their performance in the simple discrete tasks their answers were mixed. Three subjects said that area display color coding helped in the discrete tasks and three said color provided no help. Two subjects said that shape coding helped and four said that shape coding did not help in the discrete tasks.

In conclusion, then, the subjects showed a strong preference for color and/or shape coding and they uniformly believed it aided their performance in the air traffic control task. In fact, there was a significant decrease in air traffic control performance when shape or color was used to encode altitude status.

## GENERAL CONCLUSIONS

The major conclusions that can be drawn from the three new experiments have been adequately summarized in Part I of this report. This section of the report will reiterate those conclusions as they are determined by the single-code conditions and will briefly expand the earlier conclusions to include the effects of dual-code conditions.

First, the relative gain or loss associated with color coding was never very large. Whenever a relative advantage for color exceeded ten percent it most often occurred when color was used in place of letters or in place of digits in a display which had used both letters and digits. In that case, other coding variables, e.g., familiar geometric shape, often led to equally large gains relative to the letter-digit combination. The relative gain in performance which accompanied the use of color coding varied as a function of the task and the number of dimensions a coding variable employed. The largest relative gain scores generally occurred for the higher density displays.

Second, comparisons between Experiment 1 and the previously reported single-task experiments showed that the multiple tasks (with inherent task uncertainty) and variations in exposure time had no differential effects on performance. Hence, while there was often an overall change in performance levels between the combined tasks and single-task experiments, there was no effect on the relative effectiveness of color coding.

Third, there is evidence that the subject began to process the entire stimulus array as soon as it was presented, and before he knew which task he would be asked to perform. This conclusion is supported by the fact that properties of the stimulus array had significnat effects on choice reaction performance even though the stimulus array was irrelevant. Furthermore, highly practiced subjects demonstrated a strong tendency not only to process any and all potentially relevant information which was presented to them, but they also showed a very strong tendency to organize and reorganize inputs from the display. This organizing tendency occurred as a function of heterogeneity of inputs (i.e., dual-codes) and as a function of differential task demands. Performance was usually superior when there was an opportunity for differential organization of input than when there was no opportunity for information segregation and reorganization. It was also shown that color may be usefully employed as a coding variable if there is an advantage or requirement for distinguishing one class of stimuli from another class of stimuli.

Fourth, the results indicate that the use of partially redundant multidimensional coding had an effect on performance on the complex continuous task and also on the simpler discrete subtasks that were integrated with it. Whether or not there are effects is a function of the particular task in question and the dependent measure employed to monitor performance. In no case were there any effects in the integrated task context due to color coding relative to shape coding.

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